Draft Edwards Aquifer Technical Guidance Manual:

Permanent Best Management Practices

Prepared for

Texas Natural Resource Conservation Commission

By

Michael E. Barrett, Ph.D., P.E.

Center for Research in Water Resources
Bureau of Engineering Research
University of Texas at Austin

September 25, 1998

Disclaimer

The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. This draft version of the Technical Guidance Manual has not been reviewed or approved by the TNRCC; consequently, the contents do not necessarily reflect the official views or policies of the TNRCC.

Table of Contents

List of Figures

List of Tables

1 Introduction

The Edwards Rules (30 TAC Chapter 213) regulate activities having the potential for polluting the Edwards Aquifer and associated surface waters. The goals of the rules are the protection of existing and potential uses of groundwater and the maintenance of Texas Surface Water Quality Standards. The activities addressed are those that pose a threat to water quality in the recharge and transition zones. The rules apply in the Edwards Aquifer recharge, transition, and contributing zones, which includes portions of Medina, Bexar, Comal, Kinney, Uvalde, Hays, Travis and Williamson Counties.

The purpose of this document is to provide technical guidance to engineers and planners on how to meet the pollutant reduction requirements for stormwater runoff contained in the rules. In general, compliance will require the use of Best Management Practices (BMPs). BMPs include structural runoff controls, schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of water in the State. BMPs not included in this document may be used with the permission of the Director of the TNRCC based on other performance monitoring studies. The performance must be based upon objective studies or other information that are generally relied upon by professionals in the environmental protection field.

Permanent BMPs are those measures that are used to control pollution from regulated activities after construction is complete. Under 30 TAC Chapter 213, permanent BMPs must prevent pollution of surface water or stormwater that originates on-site or upgradient from the site and flows across the site. They must prevent pollution of surface water downgradient of the site, including pollution caused by contaminated stormwater runoff from the site. To the extent practicable, BMPs must maintain flow to naturally occurring sensitive features identified in the geologic assessment, executive director review, or during excavation, blasting, or construction.

Compliance with requirements of the Edwards rules will normally require the use of structural BMPs. The selected BMP or combination of BMPs must reduce the increase in total suspended solids (TSS) load associated with development by at least 80%. This manual specifies the types of BMPs that are appropriate for the central Texas area and their TSS removal efficiencies. The manual also includes the BMP design criteria and a methodology for calculating runoff capture volume that will result in the specified removal. Finally, maintenance guidelines are included to help engineers develop plans that will ensure the long-term performance of these devices..

The material is the manual is derived primarily from stormwater guidance documents developed and adopted by other regulatory bodies. Primary sources include the Lower Colorado River Authority (1998), North Central Texas Council of Governments (NCTCOG, 1993), the City of Austin (1988), and Young et al (1996).

2 BMP Applicability

2.1 Introduction

The applicability of a BMP for water quality control is dependent upon the TSS reduction required at the site and the nature of the site itself. Such factors as slope, soil type and depth, and availability of a constant supply of water, determine which BMPs may be appropriate at a site. Descriptions of the BMPs and their requirements are discussed in detail below; however, a few general statements about applicability and performance may help in the selection process.

Retention/irrigation is one of the preferred treatment systems. One of the main advantages includes water conservation in an area where water demand is increasing. In addition, this practice has the highest TSS removal efficiency (100% of the runoff captured), which means that it requires the smallest capture volume to achieve a given level of reduction.

Vegetated filter strips also perform well in certain settings such as along roads, streets and highways. The TSS removal is high enough to achieve the required 80% TSS reduction without the use of other controls. Effective implementation requires sufficient soil and rainfall to support the vegetation.

Extended detention basins offer some advantages for stormwater treatment. The maintenance requirements should be less than those of sand filter systems and they can be sized to provide protection of water quality leaving the site and address downstream erosion. The TSS removal efficiency of extended detention basins used alone may not be sufficient to achieve the required reduction depending on pre- and post-development land uses. When grassy swales are used to convey runoff to detention basins, the required reduction can normally be achieved.

Sand filters have been the primary stormwater treatment system in the Austin and San Antonio areas for a number of years. The TSS removal is high enough that they can be used as stand alone systems. Maintenance requirements may be higher than some other controls; however, they may be the best choice in areas with high impervious cover and space constraints.

Wet basins and constructed wetlands should be used with caution in this area. They offer the potential for aesthetic benefits and provide habitat for wildlife; however, supplemental water may be required at most sites to sustain the permanent pool and wetland vegetation. These systems have better nutrient removal than some other BMPs, but this often translates into increased growth of algae. Consequently, frequent algae removal may be required to maintain the aesthetic qualities.

2.2 Retention/Irrigation

Stormwater retention practices are characterized by the capture and disposal of runoff without direct release of captured flow to receiving streams. Retention practices generally exhibit excellent pollutant removal but can be fairly design and maintenance intensive. Retention/irrigation refers to the capture of stormwater runoff in a holding pond then use of the captured water quality volume for irrigation of appropriate landscape areas. Collection of roof runoff for subsequent use also qualifies as a retention/irrigation practice. This technology, which emphasizes beneficial use of stormwater runoff, is particularly appropriate for the Edwards Aquifer area, because of increasing demands on groundwater supplies for agricultural irrigation, urban water supply and spring flow maintenance.

Retention/irrigation systems represent an aggressive, highly effective approach to stormwater quality control. The goal of this technology is to roughly simulate the natural (undeveloped) hydrologic regime in which the large majority of rainfall is ultimately infiltrated and/or taken up through evapotranspiration. Pollutant removal effectiveness is high, accomplished through physical filtration of solids in the soil profile and uptake of nutrients by vegetation. The primary drawback of this approach is the potentially high maintenance requirements for the irrigation system, which must remain operational if this BMP is to function effectively.

<u>Selection Criteria</u>

- Appropriate for dryer areas where stormwater reuse can reduce demand on groundwater supplies
- Mimics natural systems by only producing discharge to surface water during large events or wet periods
- Removes 100% of the pollutants for the water quality capture volume.

<u>Limitations</u>

- Requires sufficient land for irrigation
- Irrigated areas must have sufficient soil coverage to prevent groundwater contamination
- Includes mechanical components that might increase maintenance requirements

<u>Cost</u>

Cost of the retention facility is comparable to that of an extended detention basin. Additional costs include pumps, irrigation system, and electrical power. Many areas that are appropriate for irrigation such as golf courses would require an irrigation system anyway.

2.3 Extended Detention Basins

The objectives of extended detention basins are to remove particulate pollutants and to reduce maximum runoff values associated with development to their pre-development levels. The water quality benefits are the removal of sediment and buoyant materials. Furthermore, nutrients, heavy metals, toxic materials, and oxygen-demanding materials associated with the particles also are removed. The control of the maximum runoff levels serves to protect drainage channels below the device from erosion and to reduce downstream flooding. These devices require sufficient area and hydraulic head to function properly. Detention facilities may be berm-encased areas, excavated basins, or buried tanks although the latter are not preferred in most situations (Young et al, 1996). A schematic of an extended detention basin is shown in Figure 2.1.

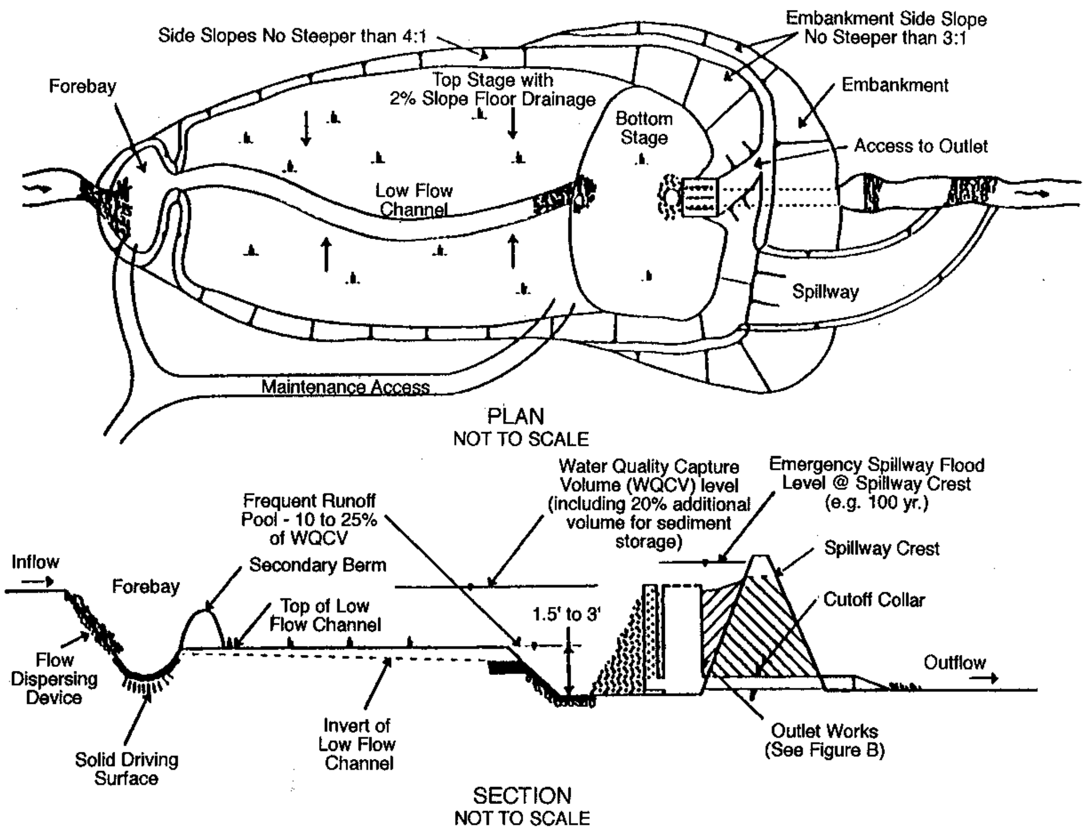

Figure 2.1 Schematic of an Extended Detention Basin (NCTCOG, 1993)

Thus, extended detention facilities are depressed basins that temporarily store a portion of stormwater runoff following a storm event. Water is controlled by means of a hydraulic control structure to restrict outlet discharge. The water quality benefits of a detention dry pond increase by extending the detention time. Excellent removal of TSS is possible if stormwater is retained for more than 24 hours. However, extended detention only slightly reduces levels of soluble phosphorus and nitrogen found in runoff. Extended detention basins normally do not have a permanent water pool between storm events. Detention facilities frequently are employed for temporary sediment control during construction, and it may be possible to retain some of these installations permanently (Young et al, 1996).

Selection Criteria (NCTCOG, 1993)

- Objective is to remove particles and associated pollutants
- Use where water availability prevents used of wet basins or where land for irrigation not available
- Use where wet basins would cause unacceptable conditions for mosquitoes

Limitations (NCTCOG, 1993)

- Limitation of the diameter of the orifice may not allow use of extended detention on small watersheds
- Requires differential elevation between inlet and outlet
- Improper design or construction by result in a mud hole
- Drainage area limited in size to 100 acres

Cost Considerations (Young et al, 1996)

This BMP is less expensive than sand filters, wet ponds, and created wetlands but more expensive than grassy swales and vegetated buffer strips. There are items to consider when designing an extended detention basin that can reduce the cost of construction. The largest single cost for the installation of an extended detention dry pond is the cost of excavation. Limiting the volume of excavation can therefore reduce costs substantially. This can be accomplished by utilizing natural depressions and topography as much as possible. In cases where a dry pond already exists at the site, it may be possible to convert the existing BMP structure to provide extended detention by increasing the storage volume and modifying the outlet structure. If feasible, the conversion can be made for a fraction of the cost of constructing a new pond.

In addition to construction costs, maintenance costs also must be included when considering an extended detention dry pond. Routine maintenance costs can include money for such items as mowing, inspections, trash removal, erosion control, and nuisance control. Non-routine maintenance costs to consider include structural repairs, sediment removal, and eventual replacement of the outlet structure. The frequency of sediment removal varies from pond to pond depending on the amount of sediment in the runoff. It is estimated, however, that extended detention dry ponds would require sediment removal about every 5 to 10 years. The estimated life of outlet structures is 25 years for corrugated metal and 50 to 75 years for reinforced concrete. The total annual cost for the above maintenance requirements, for both routine and non-routine maintenance has been estimated at three to five percent of the base construction cost.

2.4 Grassy Swales

Grassed swales are shallow vegetated channels to convey stormwater where pollutants are removed by filtration through grass and infiltration through soil (Schueler, 1992). They require shallow slopes and soils that drain well. Grassed swale designs have achieved mixed performance in pollutant removal efficiency; however, many of the studies were poorly designed. Pollutant removal capability is related to channel dimensions, longitudinal slope, and type of vegetation. Optimum design of these components will increase contact time of runoff through the swale and improve pollutant removal rates (Young et al, 1996).

Grassed swales are primarily stormwater conveyance systems. They can provide sufficient control under light to moderate runoff conditions, but their ability to control large storms is limited. Therefore, they are most applicable in low to moderate sloped areas or along highway medians as an alternative to ditches and curb and gutter drainage. Their performance diminishes sharply in highly urbanized settings, and they are generally not effective enough to receive construction stage runoff where high sediment loads can overwhelm the system (Schueler, 1992). Grassed swales can be used as a pretreatment measure for other downstream BMPs, such as extended detention basins. Enhanced grassed swales utilize check dams and wide depressions to increase runoff storage and promote greater settling of pollutants (Young et al, 1996). A cross-section of a grassy swale is presented in Figure 2.2.

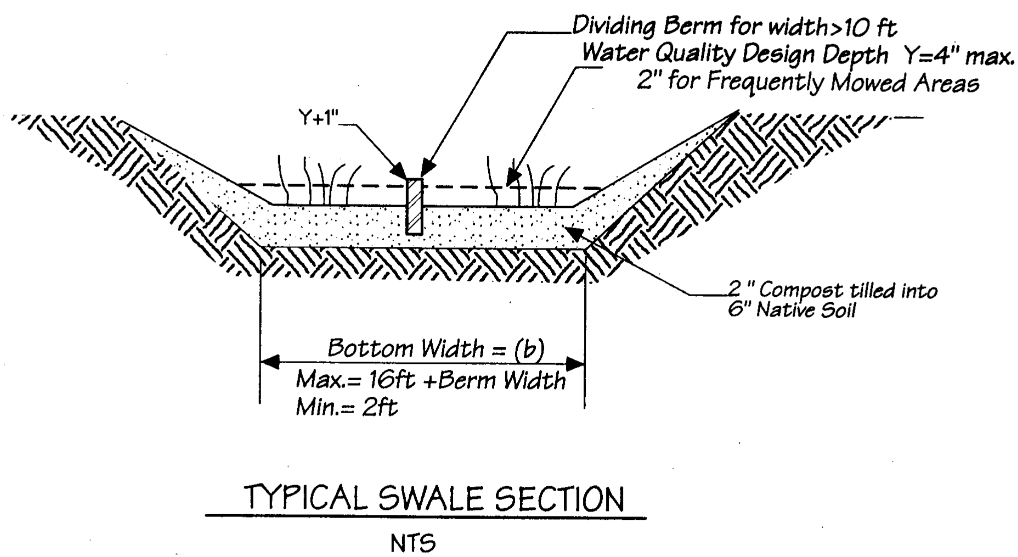

Figure 2.2 Section of a Typical Swale (King County, 1996)

Grassed swales can be more aesthetically pleasing than concrete or rock-lined drainage systems and are generally less expensive to construct and maintain. When swales are substituted for curbs and gutters, they can slightly reduce impervious areas and eliminate a very effective pollutant accumulation and delivery system. The disadvantages of this technique include the possibility of erosion and channelization over time, and the need for more right-of-way as compared to a storm drain system. When properly constructed, inspected, and maintained, the life expectancy of a swale is estimated to be 20 years (Young et al, 1996).

Selection Criteria (NCTCOG, 1993)

- Comparable performance to wet basins
- Limited to treating a few acres
- Availability of water during dry periods to maintain vegetation

The suitability of a swale at a site will depend on land use, size of the area serviced, soil type, slope, imperviousness of the contributing watershed, and dimensions and slope of the swale system. (Schueler, 1992). In general, swales can be used to serve small areas, less than 10 ac in size, with slopes no greater than 5 percent. The seasonal high water table should be at least 1 to 2 ft below the surface and buildings should be at least 10 feet from the site. Use of natural topographic lows is encouraged, and natural drainage courses should be regarded as significant local resources to be kept in use (Young et al, 1996).

Limitations (NCTCOG, 1993)

- Poor performance has occurred but this appears to be due to poor design
- Can be difficult to avoid channelization
- Cannot be placed on steep slopes
- Area required may make infeasible on industrial sites

The topography of the site should permit the design of a channel with a slope and cross-sectional area sufficient to maintain an appropriate flow velocity. Site topography may also dictate a need for additional structural controls. Recommendations for longitudinal slopes range between 2 and 6 percent. Shallower slopes can be used, if sufficient to provide adequate conveyance. Steep slopes increase flow velocity, decrease detention time, and may require energy dissipating and grade check. Steep slopes also can be managed using a series of check dams to terrace the swale and reduce the slope to within acceptable limits. The use of check dams with swales also promotes infiltration.

Cost Considerations

Swales are one of the least expensive stormwater treatment options and cost less to construct than curb and gutter drainage systems.

2.5 Vegetative Filter Strips

Filter strips, also known as vegetated buffer strips, are vegetated sections of land similar to grassed swales, except they are essentially flat with low slopes, and are designed only to accept runoff as overland sheet flow. A schematic of a vegetated buffer strip is shown in Figure 2.3. They may appear in any vegetated form from grassland to forest, and are designed to intercept upstream flow, lower flow velocity, and spread water out as sheet flow. The dense vegetative cover facilitates conventional pollutant removal through detention, filtration by vegetation, and infiltration (Young et al, 1996).

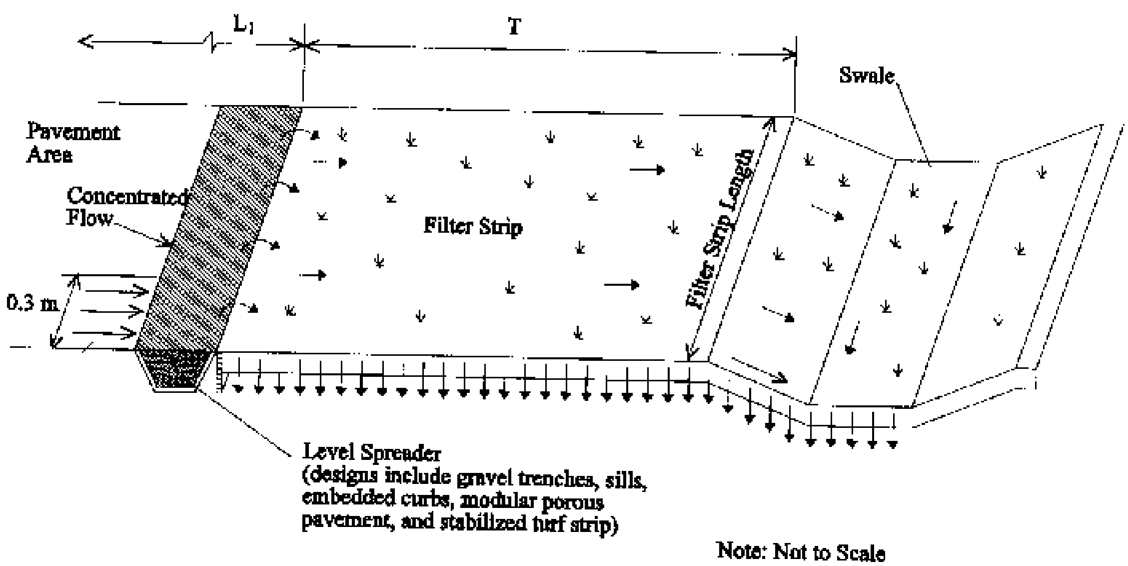

Figure 2.3 Schematic of Filter Strip/Grassy Swale (modified from Urbonas, 1992)

Filter strips cannot treat high velocity flows, and do not provide enough storage or infiltration to effectively reduce peak discharges to predevelopment levels for design storms (Schueler, 1992). This lack of quantity control favors use in rural or low-density development. The primary highway application for vegetative filter strips is along rural roadways where runoff that would otherwise discharge directly to a receiving water, passes through the filter strip before entering a conveyance system. Properly designed roadway medians and shoulders make effective buffer strips.

Flat slopes and low to fair permeability of natural subsoil are required for effective performance of filter strips. Although an inexpensive control measure, they are most useful in contributing watershed areas where peak runoff velocities are low, as they are unable to treat the high flow velocities typically associated with high impervious cover (Barrett et al., 1995).

Successful performance of filter strips relies heavily on maintaining shallow unconcentrated flow. To avoid flow channelization and maintain performance, a filter strip should:

- Be equipped with a level spreading device for even distribution of runoff,
- Contain dense vegetation with a mix of erosion resistant, soil binding species,
- Be graded to a uniform, even and relatively low slope,
- Laterally traverse the contributing runoff area (Schueler, 1987).

Filter strips can be used on an upgradient from watercourses, wetlands, or other water bodies, along toes and tops of slopes, and at outlets of other stormwater management structures. They should be incorporated into street drainage and master drainage planning (Urbonas, 1992). The most important criteria for selection and use of this BMP are soils, space, and slope.

Selection Criteria

- Soils and moisture are adequate to grow relatively dense vegetative stands.
- Sufficient space is available.
- Slope is less than 12%.
- Comparable performance to wet basins

Limitations (NCTCOG, 1993)

- Can be difficult to maintain sheet flow
- Cannot be placed on steep slopes
- Area required may make infeasible on industrial sites

Cost Considerations

Buffer strips are one of the least expensive stormwater treatment options and cost less to construct than curb and gutter drainage systems.

2.6 Sand Filter Systems

The objective of sand filters is to remove sediment and the pollutants from the first flush of pavement and impervious area runoff. The filtration of nutrients, organics, and coliform bacteria is enhanced by a mat of bacterial slime that develops during normal operations. One of the main advantages of sand filters is their adaptability; they can be used on areas with thin soils, high evaporation rates, low-soil infiltration rates, in limited-space areas, and where groundwater is to be protected (Young et al, 1996). A diagram of a sand filter system is presented in Figure 2.4.

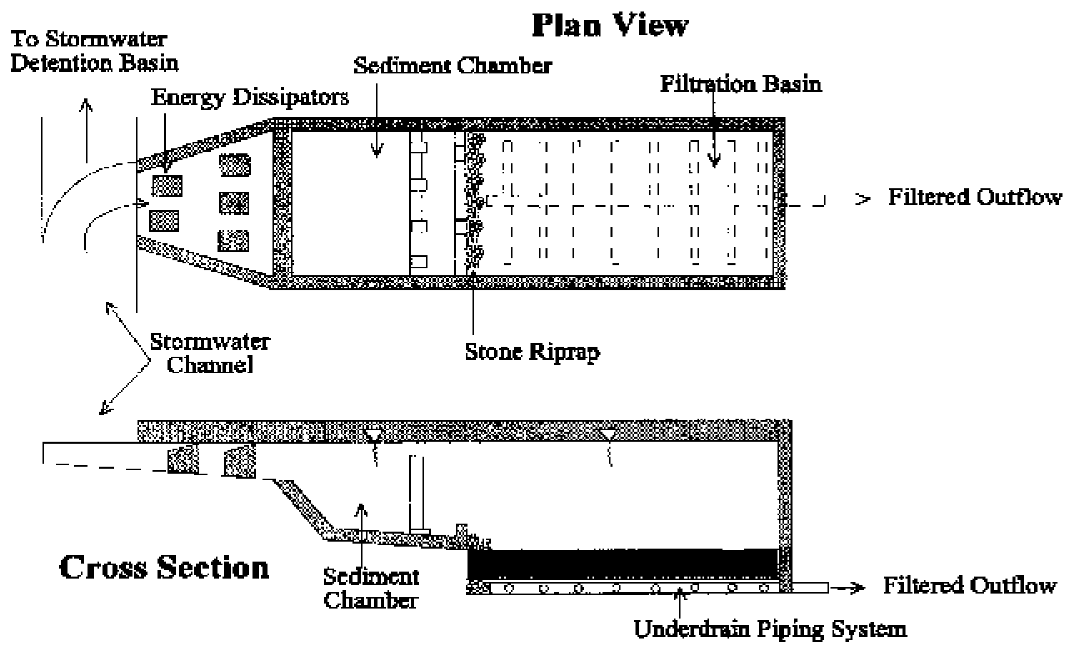

Figure 2.4 Schematic of a Sand Filter System (Young et al, 1996)

The use of slow-sand filters for the treatment of stormwater runoff is a fairly recent innovation. The filtration of water through sand as a means of improving its quality was first performed in 1829 in London to treat Thames River water. This first filter was the predecessor of the slow-sand type later developed in England and used extensively at the beginning of the 20th century in the United States for water and wastewater treatment. Over the intervening years, the use of slow-sand filters for the treatment of water and wastewater declined as improved rapid filtering and treatment technologies were developed (Young et al, 1996).

Since their original inception in Austin, Texas, hundreds of intermittent sand filters have been implemented to treat stormwater runoff. There have been numerous alterations or variations in the original design as engineers in other jurisdictions have improved and adapted the technology to meet their specific requirements. Major types include the above-mentioned Austin Sand Filter, the District of Columbia Underground Sand Filter, the Alexandria Dry Vault Sand Filter, the Delaware Sand Filter, and peat-sand filters which are adapted to provide a sorption layer and vegetative cover to various sand filter designs (Young et al, 1996).

Selection Criteria

- Appropriate for space-limited areas
- Applicable in arid climates where wet basins and constructed wetlands are not appropriate
- High TSS removal efficiency
- Can be placed underground

Limitations

- Require more maintenance that most other BMPs
- Generally require more hydraulic head to operate properly (minimum 4 feet)
- Not effective for dissolved pollutants
- High solids loads will cause the filter to clog
- Work best for relatively small, impervious watersheds
- Filters in residential areas can present aesthetic and safety problems

Cost Considerations

Filtration systems may require less land than some other BMPs, reducing the land acquisition cost; however, the structure itself is one of the more expensive BMPs. In addition, maintenance costs can be substantial.

2.7 Wet Basins

The wet basin (pond) is a facility that removes sediment, BOD, organic nutrients, and trace metals from stormwater runoff. This is accomplished by detaining stormwater using an in-line permanent pool or pond resulting in settling of pollutants. The wet basin is similar to an extended detention basin, except that a permanent volume of water is incorporated into the design (Figure 2.5). Biological processes occurring in the permanent pool aid in reducing the amount of soluble nutrients present in the water, such as nitrate and ortho-phosphorus (Schueler, 1987). Wet basins also offer flood-control benefits. Because they are designed with permanent pools, wet basins can also have recreational and aesthetic benefits (Young et al, 1996).

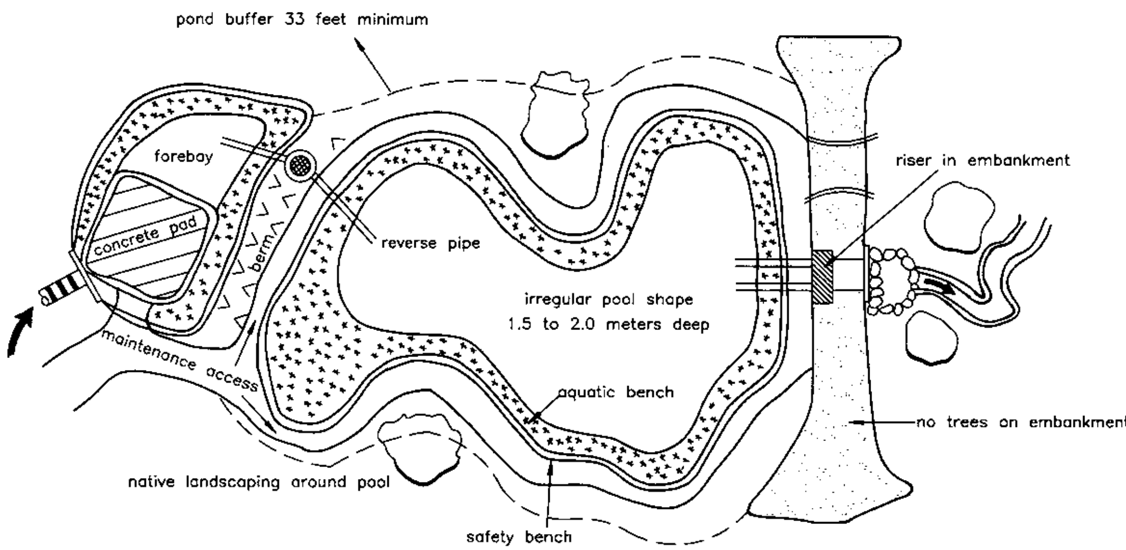

Figure 2.5 Schematic of a Wet Basin (Schueler et al, 1992)

Wet basins may be feasible for watershed areas greater than 10 ac and possessing a dependable water source. A drainage area of 1.0 mi^2 is usually the maximum drainage area where a wet pond can be installed (Schueler, 1992). It is most cost effective to use retention ponds in larger and more densely developed areas. An adequate source of water must be available to ensure a permanent pool throughout the entire year. If the wet pond is not properly maintained or the pond becomes stagnant, floating debris, scum, algal blooms, unpleasant odors, and insects may appear. Sediment removal is usually necessary after the pond has been functional for about a decade (Young et al, 1996).

Soil conditions are important for the proper functioning of the wet pond. The pond is a permanent pool, and thus must be constructed such that the water must not be allowed to exfiltrate from the permanent portion of the pool. If permeable soils exist at the site, a geomembrane or clay liner may be necessary (Young et al, 1996).

Selection Criteria (NCTCOG, 1993)

- Need to achieve high level of particulate and some dissolved contaminant removal
- Ideal for large, regional tributary areas
- Multiple benefits of passive recreation (e.g., bird watching, wildlife habitat)
- Site area greater than 10 ac

Limitations (NCTCOG, 1993)

- Concern about mosquitoes
- Cannot be placed on steep slopes
- Not normally used in arid regions where evapotranspiration greatly exceeds precipitation (which is most of the Edwards region)
- May be infeasible to site or retrofit in dense urban areas

Cost Considerations

Aquatic weed control (especially algae) is often required and the cost can be substantial to maintain aesthetic qualities when baseflow is low. The land requirements to achieve the required storage volume can also be significant. Wet basin costs are 25 to 40% greater than those reported for conventional stormwater detention.

2.8 Constructed Wetlands

Wetlands provide physical, chemical, and biological water quality treatment of stormwater runoff. Physical treatment occurs as a result of decreasing flow velocities in the wetland, and is present in the form of evaporation, sedimentation, adsorption, and/or filtration. Chemical processes include chelation, precipitation, and chemical adsorption. Biological processes include decomposition, plant uptake and removal of nutrients, plus biological transformation and degradation. Hydrology is one of the most influential factors in pollutant removal due to its effects on sedimentation, aeration, biological transformation, and adsorption onto bottom sediments (Dorman et al., 1996). The large surface area of the bottom of the wetland encourages higher levels of adsorption, absorption, filtration, microbial transformation, and biological utilization than might normally occur in more channelized watercourses (Young, et al, 1996). A schematic diagram of a constructed wetland is shown in Figure 2.6.

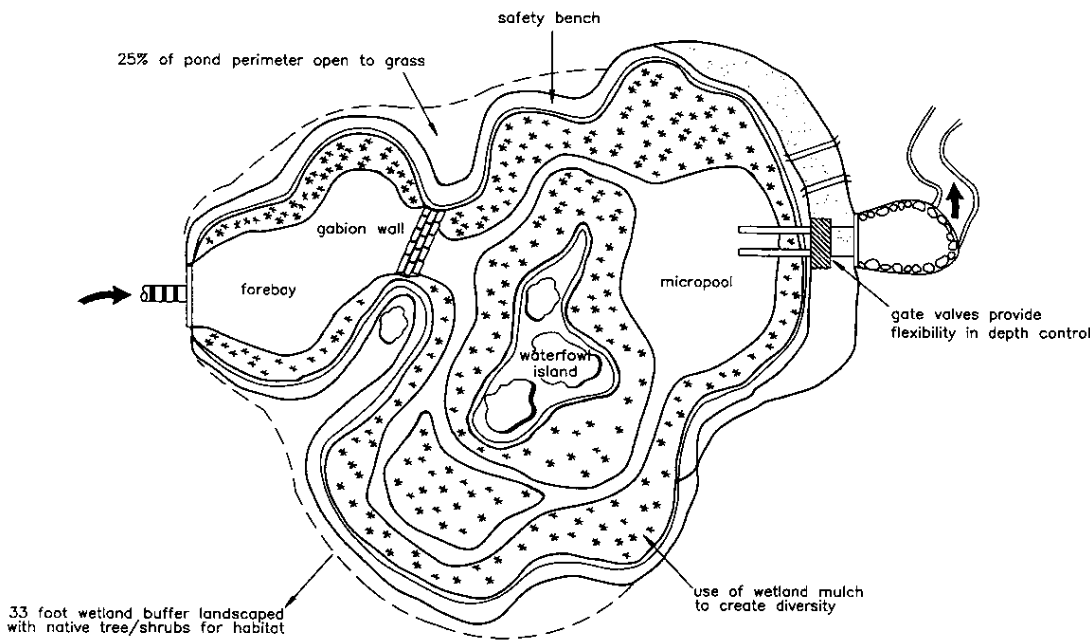

Figure 2.6 Schematic of a Constructed Wetland (Schueler et al, 1992)

Artificial wetlands offer natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal. Artificial wetlands can offer good treatment following treatment by other BMPs, such as wet ponds, that rely upon settling of larger sediment particles (Urbonas, 1992). They are useful for large basins when used in conjunction with other BMPs. Wetlands do have some disadvantages in that a continuous base flow is required. If not properly maintained, wetlands can accumulate salts and scum which can be flushed out by large storm flows. Another disadvantage is that regular maintenance, including plant harvesting, is required to provide nutrient removal. Sediment removal is also required to maintain the proper functioning of the wetland (Young et al, 1996).

The success of a wetland will be much more likely if some general guidelines are followed. The wetland should be designed such that a minimum amount of maintenance is required. This will be affected by the plants, animals, microbes, and hydrology. The natural surroundings, including such things as the potential energy of a stream or a flooding river, should be utilized as much as possible. It is necessary to recognize that a fully functional wetland cannot be established spontaneously. Time is required for vegetation to establish and for nutrient retention and wildlife enhancement to function efficiently. Also, the wetland should approximate a natural situation as much as possible, and unnatural attributes, such as a rectangular shape or a rigid channel, should be avoided (Young et al, 1996).

Site considerations should include the water table depth, soil/substrate, and space requirements. Because the wetland must have a source of flow, it is desirable that the water table is at or near the surface. This is not always possible. If runoff is the only source of inflow for the wetland, the water level often fluctuates and establishment of vegetation may be difficult. The soil or substrate of an artificial wetland should be loose loam to clay. A perennial baseflow must be present to sustain the artificial wetland. The presence of organic material is often helpful in increasing pollutant removal and retention. A greater amount of space is required for a wetland system than is required for a detention facility treating the same amount of area (Dorman et al, 1996).

Natural wetlands may not be used for stormwater treatment. A natural wetland is defined by examination of the soils, hydrology, and vegetation that are dominant in the area. Wetlands are characterized by the substrate being predominantly undrained hydric soil. A wetland may also be characterized by a substrate, which is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year. Wetlands also usually support hydrophytes, or plants that are adapted to aquatic and semi-aquatic environments (Young et al, 1996).

<u>Selection Criteria (NCTCOG, 1993)</u>

- Need to achieve high level of particulate and some dissolved contaminant removal
- Ideal for large, regional tributary areas
- Multiple benefits of passive recreation (e.g., bird watching, wildlife habitat)
- Never use natural or mitigated wetlands as a treatment device

<u>Limitations (NCTCOG, 1993)</u>

- Concern about mosquitoes
- Cannot be placed on steep slopes

- May need base flow or supplemental water to maintain wetland vegetation
- May be infeasible to site or retrofit in dense urban areas
- Nutrient release may occur during winter
- Overgrowth may lead to reduced hydraulic capacity
- Agencies may claim as wetlands and restrict maintenance

Cost Considerations

The land requirements to achieve the required storage volume are generally greater than for wet basins, because of the required shallow water depths.

3 TSS Removal and BMP Sizing Calculations

3.1 Introduction

Under 30 TAC Chapter 213, 80% of the increase in TSS load resulting from development (over background) must be removed. This chapter sets out the methodology to be used to calculate in the increase in load. The following steps explain the process used for calculating load reduction and sizing BMPs.

(1) Calculate the predevelopment TSS load based on current land use and level of development. Include in this calculation runoff which enters the property from upgradient and which will be conveyed in the proposed development's drainage system.

(2) Calculate the TSS load after development, also including the contribution from upgradient.

(3) Calculate the required TSS reduction, which is 80% of the difference of the values obtained in Steps (1) and (2).

(4) Select a BMP or combination of BMPs that are appropriate for the site.

(5) Calculate the capture volume required to obtain the 80% removal. This volume will be a function of the type of BMP and its TSS removal efficiency.

(6) If the selected BMP can not achieve the required reduction, select another BMP with higher removal efficiency and repeat Step (5).

3.2 Load Calculation

The annual pollutant load is the product of the annual runoff volume and the average TSS concentration associated with a particular land use. The following equation will be used to calculate annual load:

Equation 3.1 $$L = A \times P \times Rv \times C \times 0.226$$

where:

L = annual pollutant load (lb)
A = Contributing drainage area (ac)

P = Average annual precipitation (inches)
Rv = Runoff coefficient for the fraction of impervious cover
C = Average TSS concentration (mg/L)
0.226 = units conversion factor

The average precipitation for the each county was estimated from maps prepared by Larkin and Bomar (1983) and is shown in Table 3.1. Projects that are located in two adjacent counties should use of the average of the two counties' rainfall. The site runoff coefficient is the average annual runoff divided by the average annual precipitation. The amount of runoff from a site is primarily a function of the amount of impervious cover. The relationship between runoff coefficient and impervious cover is based on data collected by the City of Austin and is shown in Figure 3.1. The data is presented in tabular format in Table 3.2.

Table 3.1 Average Annual Rainfall by County

County	Average Annual Precipitation (in)
Bexar	30
Comal	33
Hays	33
Kinney	22
Medina	28
Travis	32
Uvalde	25
Williamson	32

Imperviousness is the percent, or decimal fraction, of the total site area covered by the sum of roads, parking lots, sidewalks, rooftops and other impermeable surfaces. Although runoff from roofs is often considered to be benign, monitoring in Texas indicates that roof runoff often contains constituent concentrations that exceed water quality standards (Chang and Crowley, 1993). In addition, TSS concentrations assigned to developed areas were based on stormwater monitoring of watersheds that included roofs and sidewalk areas. Consequently, the entire impervious area should be included in the calculations and must be captured and treated to the extent required to obtain 80% removal of the TSS load from the entire site.

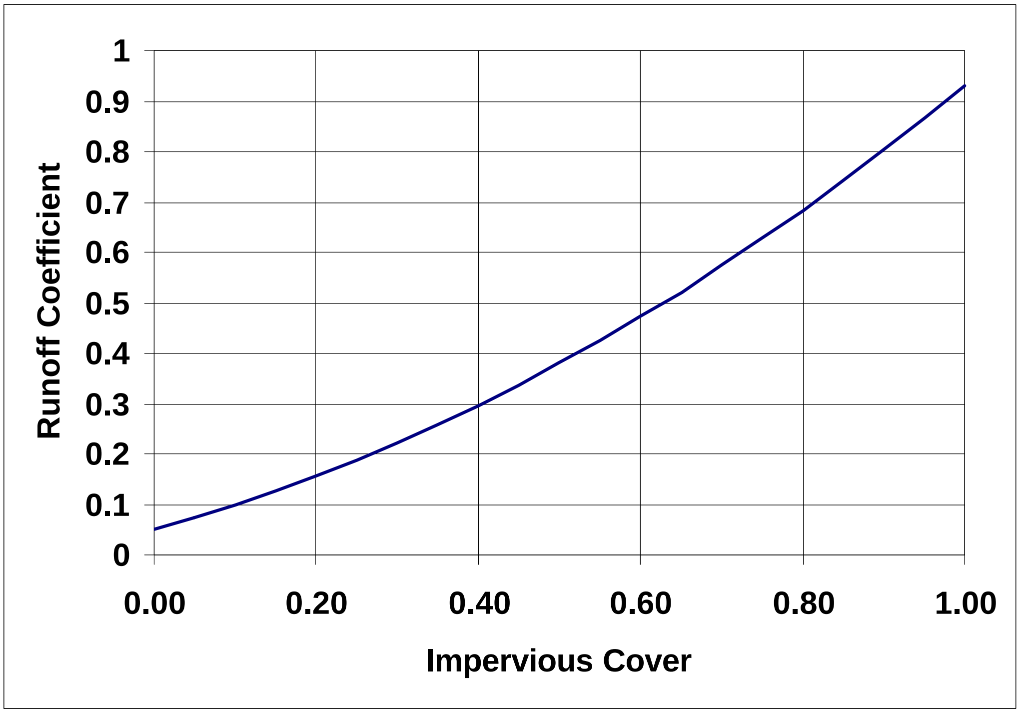

Figure 3.1 Relationship between Runoff Coefficient and Impervious Cover

Table 3.2 Listing of Runoff Coefficients for various Impervious Covers

Impervious Cover	Runoff Coefficient
0.00	0.05
0.10	0.10
0.20	0.16
0.30	0.22
0.40	0.30
0.50	0.38
0.60	0.47
0.70	0.57
0.80	0.68
0.90	0.80
1.00	0.93

The area used for calculation of annual load should be the same for background (predevelopment) and developed conditions. This area should include that portion of the tract that would flow to any proposed runoff control facility at full buildout.

3.2.1 Background Load

The background load consists of the sum of the load from any currently undeveloped portion of the proposed development and the load from any existing development on the site, even if the existing development will be demolished or replaced.

Water quality data collected by the City of Austin indicates that the average TSS concentration for undeveloped land is 55 mg/L (COA, 1997). The runoff coefficient for undeveloped areas is 0.05 (0% impervious cover). Therefore, the annual load prior to development from the currently undeveloped portion of the tract can be calculated by:

Equation 3.2

$$L = A \times P \times 0.62$$

where:

L = annual pollutant load (lb)
A = Contributing drainage area (ac)
P = Average annual precipitation (inches)

If a portion of the tract proposed for development contains existing commercial, industrial, or residential development the load from these areas can be calculated according to the methodology explained in Section 3.2.2.

3.2.2 Post Development Load

Water quality data collected by the City of Austin indicates that the average TSS concentration for developed land uses is 190 mg/L (Barrett et al, 1998a). The runoff coefficient for the developed area is determined from Figure 3.1. Therefore, the annual load after development can be calculated by:

Equation 3.3

$$L = A \times P \times R_v \times 43$$

where:

L = annual pollutant load (lb)
A = Contributing drainage area (ac)
P = Average annual precipitation (inches)
R_v = Post development runoff coefficient

3.3 Calculation of TSS Load Reduction

The load reduction required is 80% of the increase in TSS loading resulting from the proposed development. This can be expressed mathematically as:

Required Reduction = 0.8 x (postdevelopment load –predevelopment load)

The load to a proposed BMP can be calculated using Equation 3.3. Whether the entire load enters the BMP and is treated depends on whether the facility is constructed offline or online.

For BMPs such as grassy swales and vegetated buffer strips, which are online, the entire TSS load in the runoff is treated; consequently, the load reduction is calculated as:

Equation 3.4 $L_R = L_I$ x Fraction of site treated x (TSS Removal Efficiency)

Where:

L_R = Load removed (lb)
L_I = Post development load for the entire site (lb)

The load reduction for an offline BMP, such as a sand filter system, is also a function of the fraction of the stormwater load entering the facility, since some stormwater will bypass the facility once the design capture volume has been reached. Consequently, the efficiency of the device is reduced by the amount of runoff that bypasses the structure. The load reduction is calculated as:

Equation 3.5 $L_R = L_I$ x F x Fraction of site treated x (TSS Removal Efficiency)

Where:

L_R = Load removed (lb)
L_I = Post development load for the entire site (lb)
F = Fraction of the load capture by the BMP

The fraction of the load captured by the BMP should be selected so that the load removed from all proposed BMPs is at least 80% of the increase in TSS loading from the development. The fraction of the load diverted to the BMP is determined by the capture volume of the facility.

Figure 3.2 (modified from COA, 1990) demonstrates the relationship between runoff depth and load captured and treated. The values for the graph are presented in Table 3.3 as well. Figure 3.2 should be interpreted in the following manner. If the impervious cover of the proposed development is 50% and 95% of the load must be captured to satisfy Equation 3.5, then a basin must be sized to capture 0.75 inches of runoff from the site.

Table 3.3 Listing of Runoff Depth vs Load Captured for various Impervious Covers

Runoff Depth (inches)	10% IC	30% IC	50% IC	70% IC	90% IC
0	0	0	0	0	0
0.1	65	49	40	25	17
0.3	100	79	70	53	43
0.5		98	87	78	68
0.75		100	95	87	82
1			100	93	86
1.5				100	92
2					95
3					100

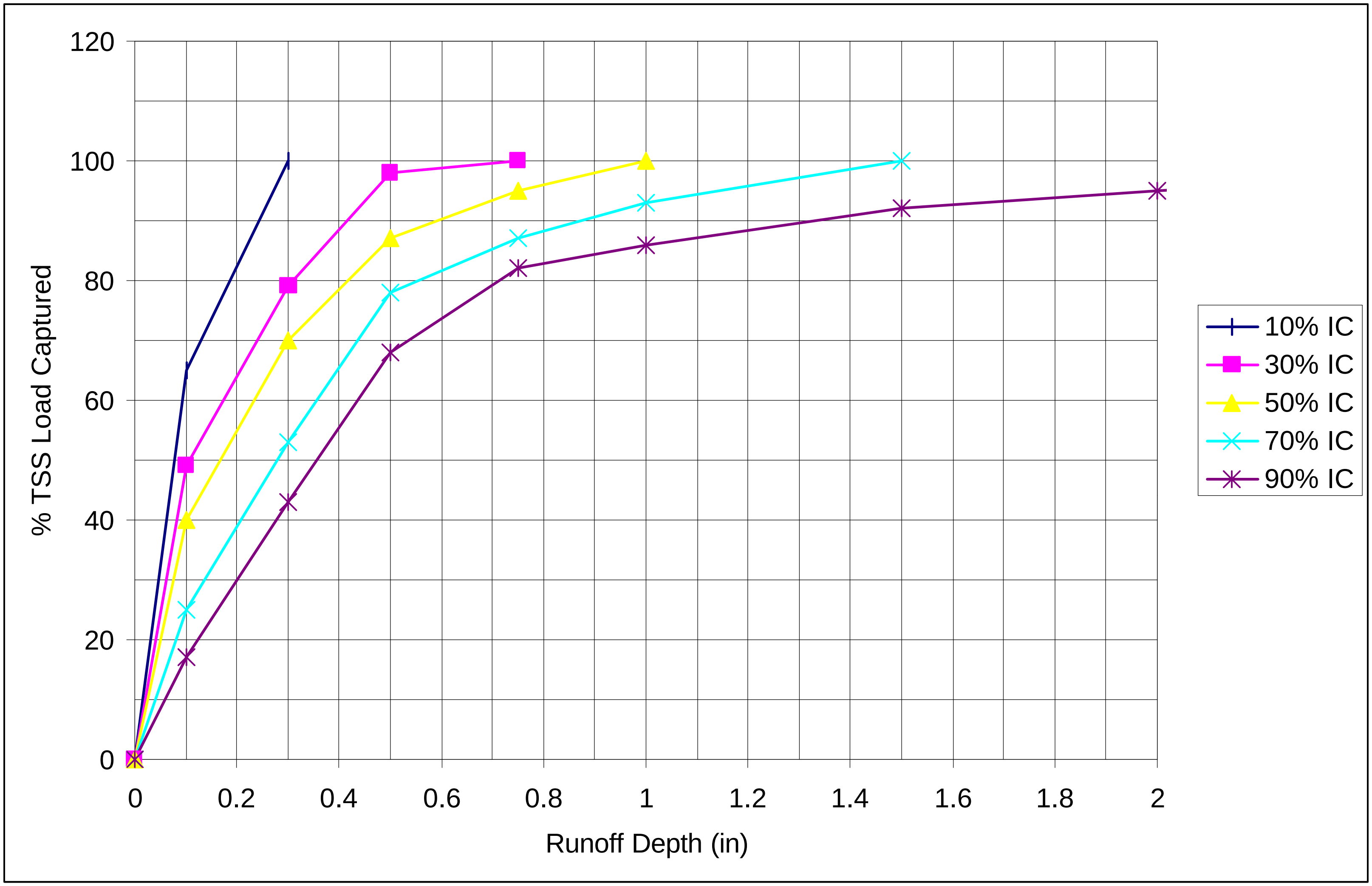

Figure 3.2 Relationship between Runoff Depth and Load Captured

3.4 TSS Removal Efficiency

The available literature was reviewed to determine reported TSS removal rates in structural stormwater controls. The primary literature sources for this manual are Barrett et al (1998b), Brown and Schueler (1997), Glick et al (1998), and Young et al (1996). The values shown in Table 3.4 represent percentage reduction in stormwater load for the runoff treated by the selected structural controls.

Table 3.4 TSS Reduction of Selected BMPs

BMP	TSS Reduction (%)
Retention/Irrigation	100
Ext. Detention Basin	75
Grassy Swales	70
Vegetated Filter Strips	85
Sand Filters	89
Wet Basins	93

3.5 TSS Removal for BMPs in Series

BMPs can be located in series to achieve the total TSS reduction required. The efficiency of each subsequent control would be expected to be less since the sediment that is most easily removed is captured in the first control; however, there is no empirical data with which to quantity the expected reduction in performance. Consequently, at this time it will be assumed that all controls operate at their optimum efficiency, so Equation 3.6 will be used to calculate total efficiency of BMPs in series:

Equation 3.6

$$E_{Tot} = [1 - ((1 - E_1) \times (1 - E_2) \times (1 - E_3))] \times 100$$

Where:

E_{Tot} = Total TSS removal efficiency of BMPs in series (%)
E_1 = Removal efficiency of first BMP (decimal fraction)
E_2 = Removal efficiency of second BMP (decimal fraction)
E_3 = Removal efficiency of third BMP (decimal fraction)

4 BMP Design Criteria

The following sections lay out the general design requirements for each of the approved BMPs. It is imperative that the contractor selected to construct these facilities is aware of these requirements and understands the importance of all elements included in the original design. All too often, the engineer responsible for developing the BMP design is not involved with the construction phase of the project and the facility as built does not function as designed. It is in the best interest of the facility owner and operator to assure that these facilities are properly constructed to improve performance, minimize maintenance, and avoid having to remove and replace the facility.

The primary purpose of BMP implementation in this area is to prevent degradation of groundwater, so the stormwater conveyance system to BMPs should be designed with this as a major objective. Consequently, stormwater conveyance should not occur on exposed bedrock. Appropriate conveyance structures include reinforced concrete pipe, concrete lined channels, and vegetated channels. If vegetated channels are incorporated in the design, they must have at least 6 inches of compacted topsoil stabilized with appropriate vegetation.

4.1 General Requirements for Maintenance Access

(1) Barrier-type fences, such as chain link, solid wood, masonry, stone or wrought iron, at least 6 feet high are required to prevent access to water quality facilities that have interior slopes greater than three to one (3H:1V). Gates, a minimum of 12 feet wide, are required to allow access of maintenance equipment.

(2) Water quality facilities shall have a permanent maintenance equipment access ramp whose slope shall not exceed four to one (4H:IV); minimum width is 10 feet for a ramp into each basin of the facilities.

(3) Drainage or drainage access easements on side lot lines shall be located adjacent to a property line and not centered on a property line.

(4) Access/drainage easements and access drives are required for detention, retention, and water quality facilities. Access drives shall be a minimum of 12 feet wide and not exceed 15% grade. Grade changes and alignment shall be considered in the design of the access drive. A turning radius not less than 50 feet is required for horizontal alignments. Grade changes shall not exceed 12% for vertical alignments. The access drive shall include a means for equipment to turn around when located more than 200 feet from a public roadway. Access drives shall be cleared, graded and stabilized.

(5) Access drives are required for area inlets and headwalls when access is proposed between single family lots or when access from any other

location exceeds 20 percent grade. Access drives shall be a minimum of 12 feet wide and not exceed 20 percent grade. Access drives shall be cleared, graded and stabilized.

(6) Points of access to water quality and detention facilities shall have a standard residential driveway approach and curb cut on the abutting street.

(7) Detention, retention and water quality facilities shall have a staging area not less than 800 square feet in area if the storage volume of the pond exceeds 2,000 cubic feet. The staging area shall be located adjacent to the water quality facility and access drive, and be within an access easement. The staging area shall be cleared, graded and revegetated, with slopes not exceeding 10% in any direction.

(8) All pond bottoms, side slopes, and earthen embankments shall be compacted to 95 percent of maximum density. Side slopes for earthen embankments shall not exceed three to one (3H:1V). Rock slopes may exceed these limits if a geotechnical report warrants a deviation. Actual field conditions may override the geotechnical report. Expansion joints on free standing walls shall have water tight seals as needed. Earthen pond and channel bottoms must have slopes greater than 2%.

4.2 Basin Lining Requirements

Impermeable liners should be used for water quality basins (retention, extended detention, sand filters, wet ponds and constructed wetlands) located over the recharge zone and in areas with the potential for groundwater contamination. Impermeable liners may be clay, concrete or geomembrane. If geomembrane is used, suitable geotextile fabric should be placed on the top and bottom of the membrane for puncture protection and the liners covered with a minimum of 6 inches of compacted topsoil. The topsoil should be stabilized with appropriate vegetation. Clay liners should meet the specifications in Table 4.1 and have a minimum thickness of 12 inches.

Table 4.1 Clay Liner Specifications (COA, 1997)

Property	**Test Method**	**Unit**	**Specification**
Permeability	ASTM D-2434	cm/sec	1×10^{-6}
Plasticity Index of Clay	ASTM D-423 & D-424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of Standard Density

If a geomembrane liner is used it shall have a minimum thickness of 30 mils and be ultraviolet resistant. The geotextile fabric (for protection of geomembrane) should be nonwoven geotextile fabric and meet the specifications in Table 4.2.

Table 4.2 Geotextile Fabric Specifications (COA, 1997)

Property	**Test Method**	**Unit**	**Specification (min)**
Unit Weight		oz/yd^2	8
Filtration Rate		in/sec	0.08
Puncture Strength	ASTM D-751	lb	125
Mullen Burst Strength	ASTM D-751	psi	400
Tensile Strength	ASTM D-1682	lb	200
Equiv. Opening Size	US Sieve	No.	80

4.3 Retention/Irrigation

Capture of stormwater in retention/irrigation systems can be accomplished in virtually any kind of runoff storage facility ranging from fully dry, concrete-lined to vegetated with a permanent pool, thus design of the storage system can be quite flexible and allows for excellent aesthetic appeal. The pump and wet well system should be automated with a rainfall sensor to allow for irrigation only during periods when required infiltration rates can be realized.

<u>Design Criteria</u>

(1) *Runoff Storage Facility Configuration and Sizing* - Design of the runoff storage facility is flexible as long as an appropriate pump and wet well system can be accommodated. For retention facilities, this volume shall be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities.

(2) *Pump and Wet Well System* - A reliable pump, wet well, and rainfall sensor system must be used distribute the water quality volume. System specifications must be approved by the TNRCC. These systems should be similar to those used for wastewater effluent irrigation, which are commonly used in areas where "no discharge" wastewater treatment plant permits are issued.

(3) *Basin Lining* – The basin lining should conform to the specifications described in Section 4.2.

(4) *Detention Time* - The irrigation schedule should allow for complete drawdown of the water quality volume within 72 hours. Irrigation should not begin within 12 hours of the end of rainfall so that direct storm runoff has ceased and soils are not saturated. Consequently, the length of the active irrigation period is 60 hours. Irrigation also should not occur during subsequent rainfall events.

(5) *Irrigation System* - Generally a spray irrigation system is required to provide an adequate flow rate for timely distribution of the water quality volume. Alternative irrigation approaches are acceptable but must be approved by TNRCC.

(6) *Irrigation Site Criteria* – The area selected for irrigation must be pervious, on slopes of less than 10%. A geological assessment is required for proposed irrigation areas to assure that there is sufficient soil cover and no recharge features that could allow the water to directly enter the aquifer. Optimum sites for irrigation include recreational and greenbelt areas as

well as landscaping in commercial developments.

(7) *Irrigation Area* – The irrigation rate must be low enough so that the irrigation does not produce any surface runoff; consequently, the irrigation rate may not exceed the permeability of the soil. The minimum required irrigation area should be calculated using the following formula:

$$A = \frac{12 \times V}{T \times r}$$

where:

A = area required for irrigation (ft^2)
V = water quality volume (ft^3)
T = period of application (60 hr)
r = Permeability (in/hr)

The permeability of the soils in the area proposed for irrigation will be determined from county soil surveys prepared by the Soil Conservation Service. If a range of permeabilities is reported, the minimum value will be assumed in the absence of representative, site-specific soil test results documenting a different rate. If no permeability data is available, a value of 0.1 inches/hour should be assumed.

It should be noted that the minimum area requires continuous irrigation for 60 hours at low rates to use the entire water quality volume. This intensive irrigation may be harmful to vegetation that is not adapted to long periods of saturated conditions. In practice, a much larger irrigation area will provide better use of the retained water and promote a healthy landscape.

(8) *Offline Design* - The basin shall be designed as an offline facility with a splitter structure to isolate the water quality volume. The splitter box shall be designed to convey the 25-year event without causing overtopping of the basin side slopes.

(9) *Safety Considerations* - Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate dropoffs and other hazards. Earthen side slopes should not exceed 3:1 (H:V) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. If the facility is fenced, gates must be provided to allow access for inspections and maintenance.

(10) *Landscaping Plan* - A landscaping plan shall be provided indicating how aquatic and terrestrial areas will be stabilized

4.4 Extended Detention Basins

Extended detention facilities capture and temporarily detain the water quality volume. They are intended to serve primarily as settling basins for the solids fraction and as a means of limiting downstream erosion by controlling peak flow rates during erosive events. Extended detention facilities may be constructed either online or offline.

Enhanced extended detention basins are designed to prevent clogging of the outflow structure and re-suspension of captured sediment; and to provide enhanced dissolved pollutant removal performance. The enhanced extended detention design typically incorporates a sediment forebay near the inlet, a micropool near the outlet, and a non-clogging outflow structure, such as a notched weir or orifice protected by a trash rack, or a perforated riser pipe protected by riprap.

Due to their relatively large land requirements and some practical difficulties associated with detaining the water quality volume for the necessary period, extended detention ponds are generally best suited to drainage areas greater than 10 acres. In addition, extended detention basins tend to accumulate debris deposits rapidly, making regular maintenance necessary to minimize aesthetic and performance problems. However, with careful design, particularly of the sediment forebay and outlet structure, they can be used effectively in any size drainage area. Extended detention facilities can readily be combined with flood and erosion control detention facilities by providing additional storage above the water quality volume.

<u>Design Criteria</u>

Estimating the appropriate dimensions of a BMP facility is largely based on a trial and error process in which the designer tries to fit the required BMP volume so that it works well with the site. Each site has its own unique limiting factors. Some constraints other than the existing topography include, but are not limited to, the location of existing and proposed utilities, depth to bedrock, and location and number of existing trees. The designer can analyze possible basin configurations by varying the surface area and depth and then determining the corresponding available storage (Young et al, 1996).

In order to enhance the effectiveness of BMP basins, the dimensions of the basin must be sized appropriately. Merely providing the required storage volume will not ensure maximum constituent removal. By effectively configuring the basin, the designer will create a long flow path, promote the establishment of low velocities, and avoid having stagnant areas of the basin. To promote settling and to attain an appealing environment, the design of BMP basin should consider the length to width ratio, cross-sectional areas, basin slopes and pond configuration, and aesthetics (Young et al, 1996).

(1) *Facility Sizing* - The required water quality volume is calculated as discussed in Section 3.6. For extended detention facilities, this volume

shall be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. If a micropool is included in the design, it should be able to store 15 to 25% of the capture volume.

(2) *Basin Configuration* – A high aspect ratio improves the performance of detention basins; consequently, the outlets must be placed to maximize the flowpath through the facility. The ratio of flowpath length to width from the inlet to the outlet should be at least 2:1. The flowpath length is defined as the distance from the inlet to the outlet as measured at the surface. The width is defined as the mean width of the basin. Basin depths optimally range from 2 to 5 ft. The basin must include a sediment forebay to provide the opportunity for larger particles to settle out. The forebay volume should be about 10% of the water quality volume.

Both conventional and enhanced ED ponds should be designed with a dual stage configuration as shown in Figure 4.1 and Figure 4.2. Stage I is intended to serve primarily as a sediment forebay for gross particulates. Stage II is generally planted with vegetation adaptable to periodic inundation and may contain a permanent micropool for enhanced extended detention. Stage II is intended to provide additional sedimentation and some nutrient removal with the enhanced ED pond design. The design depth of Stage I should be 2-5 feet. A stabilized low flow channel is required to convey low flows through Stage I to Stage II. Rock riprap shall be utilized to reduce velocities and spread the flow into the Stage II pond. The channel should maintain a longitudinal slope of 2%-5%. The lateral slope across Stage I toward the low flow channel should be 1.0-1.5%. The bottom of Stage II should be 1.5 - 3.0 feet lower than the bottom of Stage I. The extended detention basin is optimally designed to have a gradual expansion from the inlet toward the middle of the facility and a gradual contraction toward the basin outfall.

(3) *Pond Side slopes* - Side slopes of the pond shall be 3:1 or flatter for grass stabilized slopes. Slopes steeper than 3:1 must be stabilized with an appropriate slope stabilization practice.

(4) *Basin Lining* – Basins must be constructed to prevent possible contamination of groundwater below the facility. Basin linings should conform to guidelines contained in Section 4.2.

(5) *Basin Inlet* – Energy dissipation is required at the basin inlet to reduce resuspension of accumulated sediment and to reduce the tendency for short-circuiting.

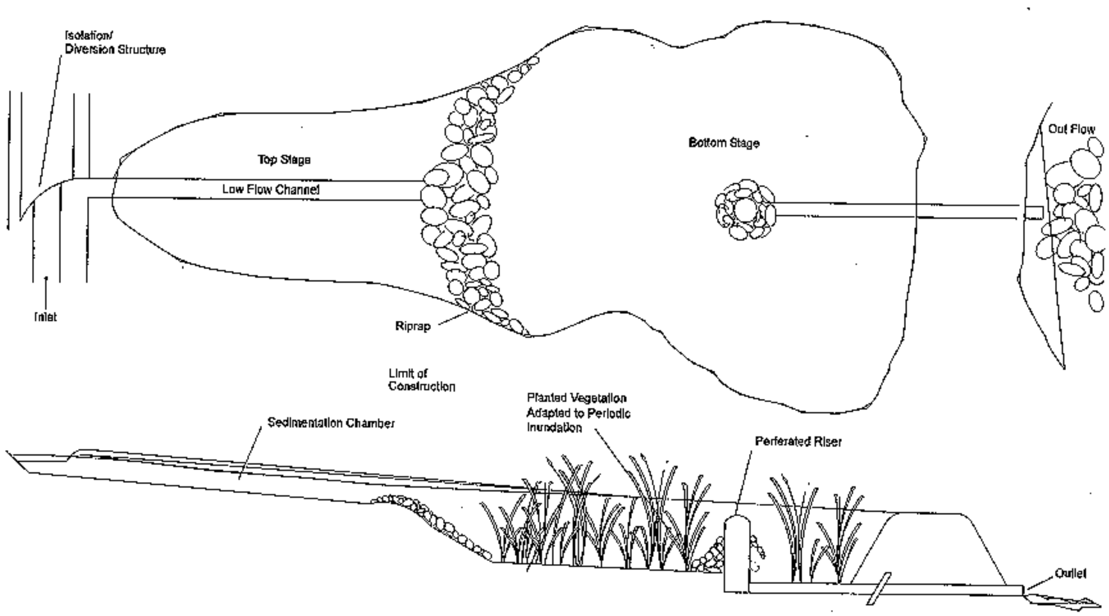

Figure 4.1 Schematic of a two stage Extended Detention Basin (LCRA, 1998)

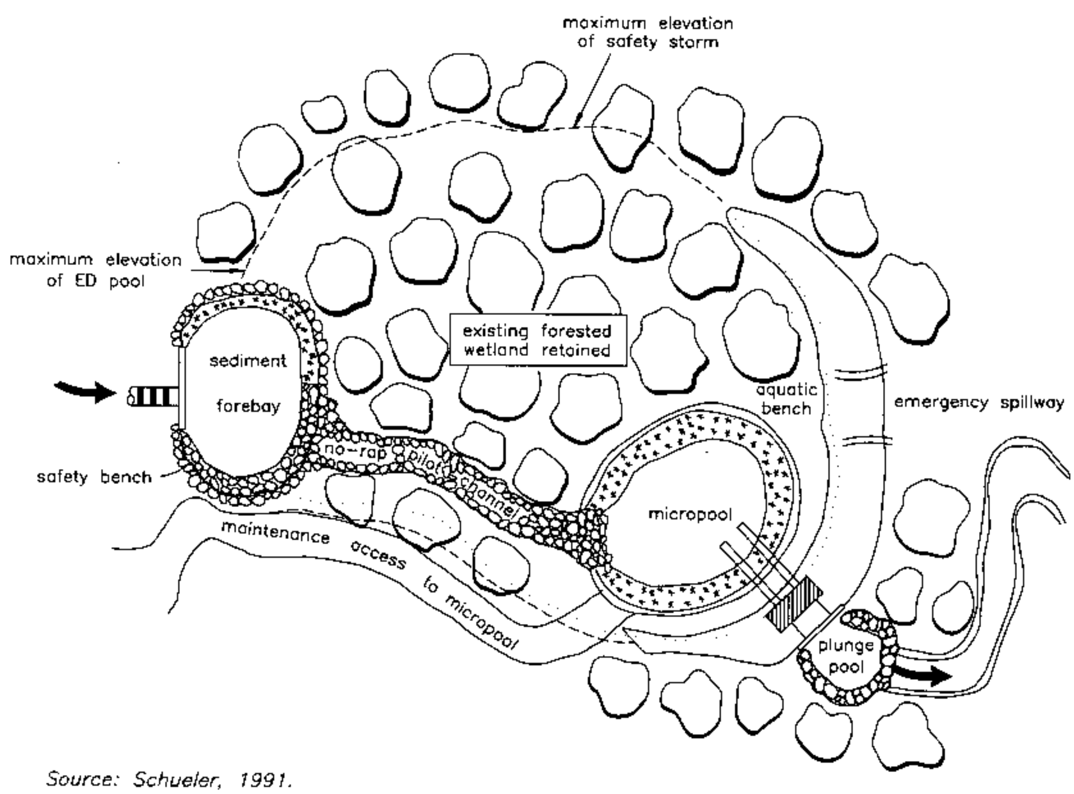

Figure 4.2 Schematic of an Enhanced Extended Detention Basin

(6) *Outflow Structure* - Figure 4.3 presents a possible outflow structure configuration for extended detention facilities. A reverse slope outflow pipe design is preferred if a second stage micropool is provided in the facility. Otherwise, the facility's drawdown time shall be regulated by a gate valve or orifice plate located downstream of the primary outflow opening. In general, the outflow structure shall have a trash rack or other acceptable means of preventing clogging at the entrance to the outflow pipes.

The outflow structure shall be sized to allow for complete drawdown of the water quality volume in 72 hours. No more than 50 percent of the water quality volume shall drain from the facility within the first 24 hours. The outflow structure should be fitted with a valve so that discharge from the basin can be halted in case of a accidental spill in the watershed. This same valve also can be used to regulate the rate of discharge from the basin.

The facility shall have a separate drain pipe with a manual valve that can completely or partially drain the pond for maintenance purposes. To allow for possible sediment accumulation, the submerged end of the pipe should be protected, and the drain pipe should be sized one pipe schedule higher than the calculated diameter needed to drain the pond within 24 hours. The valves shall be located at a point where they can be operated in a safe and convenient manner.

For online facilities, the principal and emergency spillways must be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the 100-year flood.

(6) *Vegetation* - The facility shall be planted and maintained to provide for a full and robust vegetative cover. The following wet tolerant species are recommended for planting within the Stage II area:

- Bushy Bluestem
- Sedges
- Cyperus
- Switch Grass
- Spike Rush
- Green Sprangletop
- Indian Grass
- Bullrush
- Scouring Rush
- Eastern Gamma
- Dropseed lris

A landscaping plan shall be provided indicating how aquatic and terrestrial areas will be stabilized. If wetlands element are included in the facility, design guidance is provided in "Design of Stormwater Wetlands Systems (Schueler, 1992). A minimum 25-foot vegetative buffer area should extend away from the top slope of the pond in all directions.

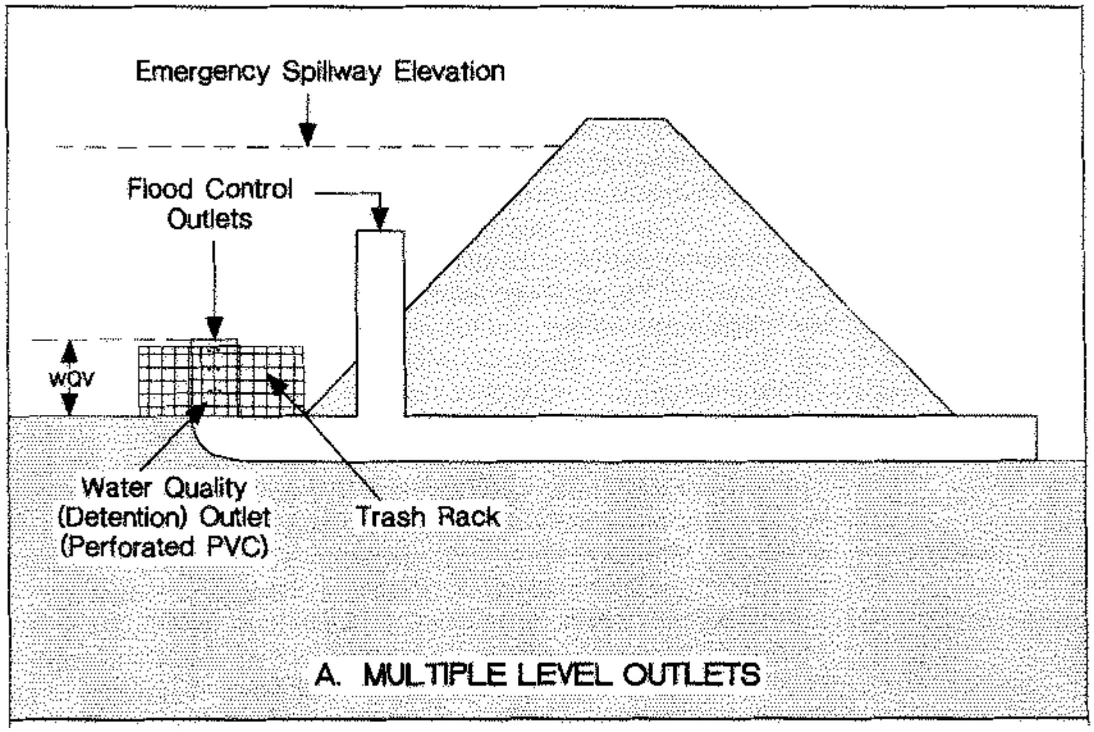

Figure 4.3 Schematic of Detention Basin Outlet Structure

(7) *Splitter Box* - When the pond is designed as an offline facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, shall be designed to convey the 25-year event while providing at least1.0 foot of freeboard along pond sideslopes.

(8) *Erosion Protection at the Outfall* - For online facilities, special consideration should be given to the facility's outfall location. Flared pipe end sections that discharge at or near the stream invert are preferred. The channel immediately below the pond outfall shall be modified to conform to natural dimensions, and lined with large riprap placed over filter cloth. A stilling basin may be required to reduce flow velocities from the primary spillway to non-erosive velocities.

(9) *Safety Considerations* - Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate dropoffs and other hazards. Earthen sideslopes should not exceed 3:1 (H:V) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. The primary spillway opening must not permit

access by small children. Outfall pipes above 48 inches in diameter should be fenced.

(10) *Embankment* - At least 10 percent extra fill should be placed on the embankment to account for possible settling.

4.5 Grassy Swales

A grassy swale is a sloped, vegetated channel or ditch that provides both conveyance and water quality treatment to stormwater runoff. Biofiltration is the simultaneous process of filtration, particle settling, adsorption, and biological uptake of pollutants in stormwater that occurs when runoff flows over and through vegetated areas.

General Criteria (WSDOT, 1995)

(1) The swale should have a length of 200 feet. The maximum bottom width is 10 feet unless a dividing berm is provided (Figure 2.2). The depth of flow must not exceed 4 inches during a 1 inch/hour storm

(2) The channel slope should be at least 1 percent and no greater than 5 percent.

(3) The swale can be sized as both a treatment facility for the design storm and as a conveyance system to pass the peak hydraulic flows of the 100-year storm if it is located "on-line."

(4) The ideal cross-section of the swale should be a trapezoid. The side slopes should be no steeper than 3:1.

(5) Roadside ditches should be regarded as significant potential swale/buffer strip sites and should be utilized for this purpose whenever possible.

(6) If flow is to be introduced through curb cuts, place pavement slightly above the elevation of the vegetated areas. Curb cuts should be at least 12 inches wide to prevent clogging.

(7) Swales must be vegetated in order to provide adequate treatment of runoff.

(8) It is important to maximize water contact with vegetation and the soil surface. For general purposes, select fine, close-growing, water-resistant grasses.

(9) Swales should generally not receive construction-stage runoff. If they do, presettling of sediments should be provided. Such swales should be evaluated for the need to remove sediments and restore vegetation following construction.

(10) If possible, divert runoff (other than necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, cover graded and seeded areas with suitable erosion control materials.

Design Procedure

(1) Determine the peak flow rate to the swale from a storm producing a constant rainfall rate of 1 inch/hour.

(2) Determine the slope of the swale. This will be somewhat dependent on where the swale is placed. The slope should be at least 1 percent and shall be no steeper than 5 percent.

(3) Select a swale shape. Trapezoidal is the most desirable shape; however, rectangular and triangular shapes can be used. The remainder of the design process assumes that a trapezoidal shape has been selected.

(4) Use Manning's Equation to estimate the bottom width of the swale. Manning's Equation for English units is as follows:

$$Q = \frac{1.49}{n} AR^{2/3} S^{0.5}$$

Where:

Q = flow (cfs)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius of flow cross-section (ft)
S = longitudinal slope of swales (ft/ft)
n = Manning's roughness coefficient (0.20 for typical swale)

For a trapezoid, this equation cannot be directly solved for bottom width. However, for trapezoidal channels that are flowing very shallow the hydraulic radius can be set equal to the depth of flow. Using this assumption, the equation can be altered to:

$$b = \frac{0.134Q}{y^{1.67} S^{0.5}} - zy$$

Where:
b = bottom width
y = depth of flow
z = the side slope of the swale in the form of z:1

Typically the depth of flow is selected to be 4 inches (100 mm). It can be set lower but doing so will increase the bottom width. Sometimes when the flow rate is very low the equation listed above will generate a negative value for b. Since it is not possible to have a negative bottom width, the bottom width should be set to 2 feet when this occurs. Swales are limited to a maximum bottom width of 10 feet. If the required bottom width is greater than 10 feet, parallel swales should be used in conjunction with a device that splits the flow and directs the proper amount to each swale.

(5) Calculate the cross-sectional area of flow for the given channel using the calculated bottom width and the selected side slopes and depth.

(6) Calculate the velocity of flow in the channel using:

$$V = Q / A$$

If V is less than or equal to 1 ft/sec, the swale will function correctly with the selected bottom width. Proceed to design step 7. If V is greater than 1 ft/sec, the swale will not function correctly. Increase the bottom width, recalculate the depth using Manning's Equation and return to design step 5.

(7) Select a location where a swale with the calculated width and a length of 200 feet will fit. If a length of 200 feet is not possible, the width of the swale should be increased so that the area of the swale is the same as if a 200-foot length had been used.

(8) Select a vegetation cover suitable for the site.

(9) Determine the peak flow rate to the swale during the 100-year 24-hour storm. Using Manning's Equation, find the depth of flow (typically n = 0.04 during the 100-year flow). The depth of the channel should be 1 foot (300 mm) deeper than the depth of flow.

4.6 Vegetative Filter Strips

Many of the general criteria applied to swale design apply equally well to vegetated filter strips. The general design goal is to produce uniform, shallow overland flow across the entire filter strip.

(1) The slope and length of the filter strip (parallel to the direction of flow) are functions of the size of the area contributing flow to the strip. For a storm with a constant rainfall rate of 1.0-inch/hour, the product of water depth in the strip (feet) times the velocity (ft/s) should not exceed 0.0015. Water depth in the strip should be calculated using the Manning equation, with a Manning's n of 0.2. As an example, a highway 50 feet wide draining to both sides of the road would require a strip 14 feet wide on each side, if the slope were 12%. The maximum slope of a filter strip should not exceed 15 percent.

(2) The area to be used for the strip will be free of gullies or rills that can concentrate overland flow (Schueler, 1987).

(3) The top edge of the filter strip along the pavement will be designed to avoid the situation where runoff would travel along the top of the filter strip, rather than through it. Berms may be placed at 15 to 30 m (50 to 100 ft) intervals perpendicular to the top edge of the strip to prevent runoff from bypassing it.

(4) Top edge of the filter strip will be level, otherwise runoff will tend to form a channel in the low spot.

(5) Filter strips should be landscaped after other portions of the project are completed.

4.7 Sand Filter Systems

Since the mid-1980's, sand filtration has been the predominant nonpoint source water quality management practice used in the Austin, Texas area. Sand filters tend to have good longevity due to their offline design and the high porosity of the sand media. However, without proper maintenance, sand filters are prone to clogging, which dramatically reduces performance and can lead to nuisances associated with standing water. Pollutant removal is achieved primarily by straining pollutants through the filtration media, settling of larger solids on the top of the sand bed, and, if the filter maintains a grass cover crop, through plant uptake. Sand filters often are perceived to have negative aesthetic appeal, especially when not maintained, thus landscaping and pond configuration design should be carefully considered.

If the sand filter design includes a wall with a riser pipe between the sedimentation and filtration chambers, then the sedimentation basin will be sized to contain the entire design capture volume. If the two chambers are separated by gabion baskets or similar porous structures, then the sum of the volumes of the sedimentation and filtration chambers must equal the designed capture volume.

<u>Design Criteria</u>

(1) *Capture Volume* - The required capture volume is dependent on the characteristics of the contributing drainage area. The method for calculation of required water quality volume is specified in Section 3.0 of this manual. For sand filter systems, this volume should be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities.

(2) *Basin Geometry* – The water depth in the sedimentation basin when full should be at least 2 feet and no greater than 10 feet. The minimum average surface area for the sand filter (Af) is calculated from the following terms:

$$Af=WQV/18$$

Af = minimum surface area for the filtration basin in square feet

WQV = water quality volume in cubic feet

(3) *Sand and Gravel Configuration* - The sand filter is constructed with 18 inches of sand overlying 6 inches of gravel. The sand and gravel media are

separated by permeable geotextile fabric and the gravel layer is situated on geotextile fabric. Four-inch perforated PVC pipe is used to drain captured flows from the gravel layer. A minimum of 2 inches of gravel must cover the top surface of the PVC pipe. Figure 4.4 presents a schematic representation of a standard sand bed profile.

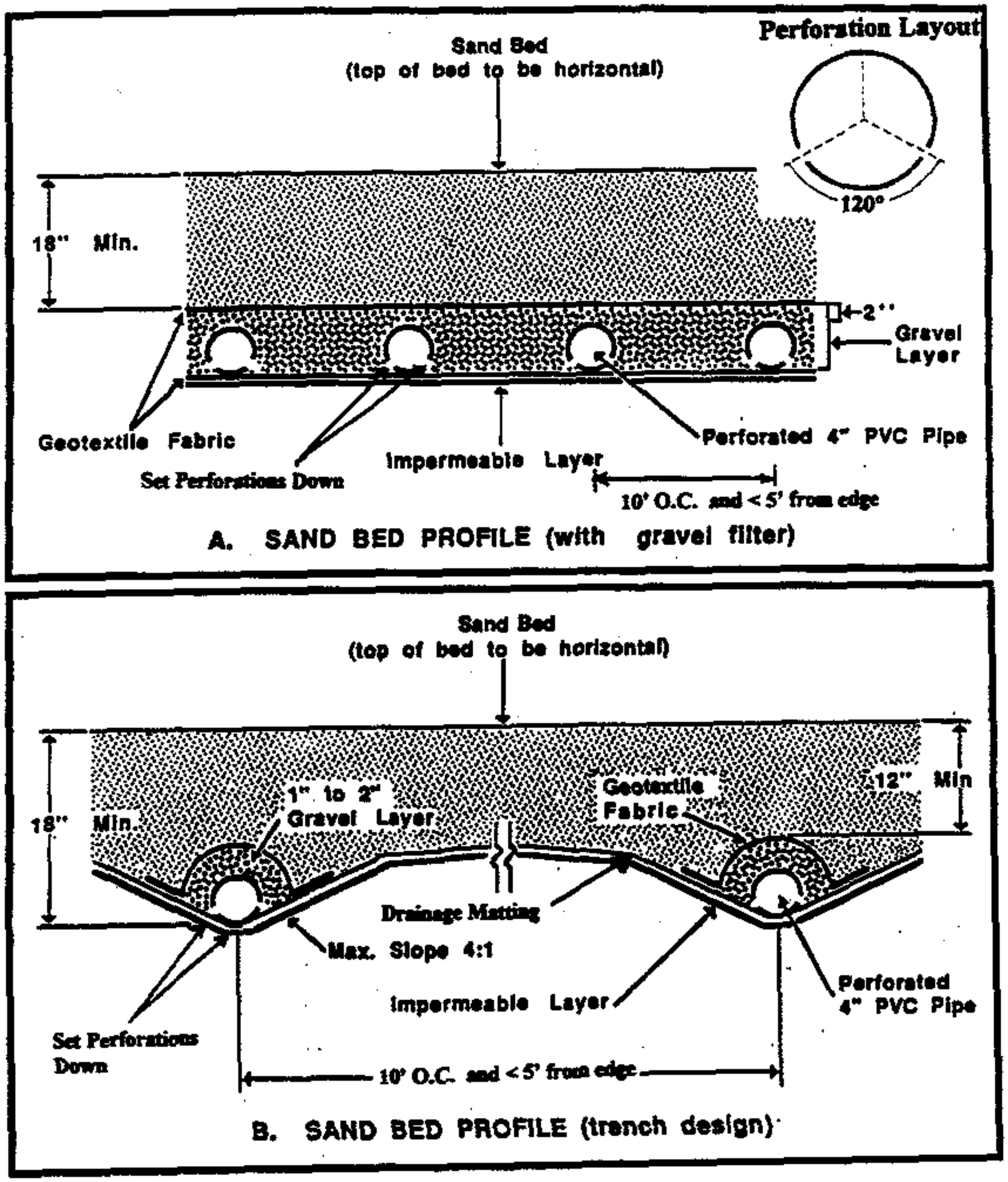

Figure 4.4 Schematic of Sand Bed Profile

(4) *Sand Properties* – to be determined

(5) *Underdrain Pipe Configuration* - The underdrain piping shall consist of a main collector pipe with minimum diameter of 4 inches and two or more lateral branch pipes. The lateral branch pipes shall have a minimum slope of 1 percent (1/8 inch per foot) and be spaced at intervals of no more than 10 feet. There shall be no fewer than two lateral branch pipes. Each individual underdrain pipe shall have a cleanout access location. All piping is to be Schedule 40 PVC. The maximum spacing between rows of perforations should not exceed 6 inches.

(6) *Basin Lining* – The basin lining should conform to the specifications described in Section 4.2.

(7) *Flow Splitter* - The inflow structure to the sedimentation chamber shall incorporate a flow-splitting device capable of isolating the capture volume and bypassing the 25-year peak flow around the pond with the sedimentation/filtration pond full.

(8) *Basin Inlet* – Energy dissipation is required at the sedimentation basin inlet so that flows entering the basin shall be distributed uniformly and at low velocity in order to prevent resuspension and encourage quiescent conditions necessary for deposition of solids.

(9) *Sedimentation Pond Outlet Structure* - The outflow structure from the sedimentation chamber shall be (1) an earthen berm; (2) a concrete wall; or (3) a rock gabion. Gabion outflow structures shall extend across the full width of the facility such that no short-circuiting of flows can occur. The gabion rock should be 4 inches in diameter. The receiving end of the sand filter shall be protected (splash pad, riprap, etc.) such that erosion of the sand media does not occur. When a pipe is used to connect the sedimentation and filtration basins (example in Figure 4.5), a valve must be included to isolate the sedimentation basin in case of a hazardous material spill in the watershed. The control for the valve must be accessible at all times, including when the basin is full.

(10) *Sand Filter Discharge* – If a gabion structure is used to separate the sedimentation and filtration basins, a valve must installed so that discharge from the BMP can be stopped in case runoff from a spill of hazardous material enters the sand filter. The control for the valve must be accessible at all times, including when the basin is full.

(11) *Maximum Drawdown Time* - Sand filtration BMPs shall be designed to drawdown within 48 hours.

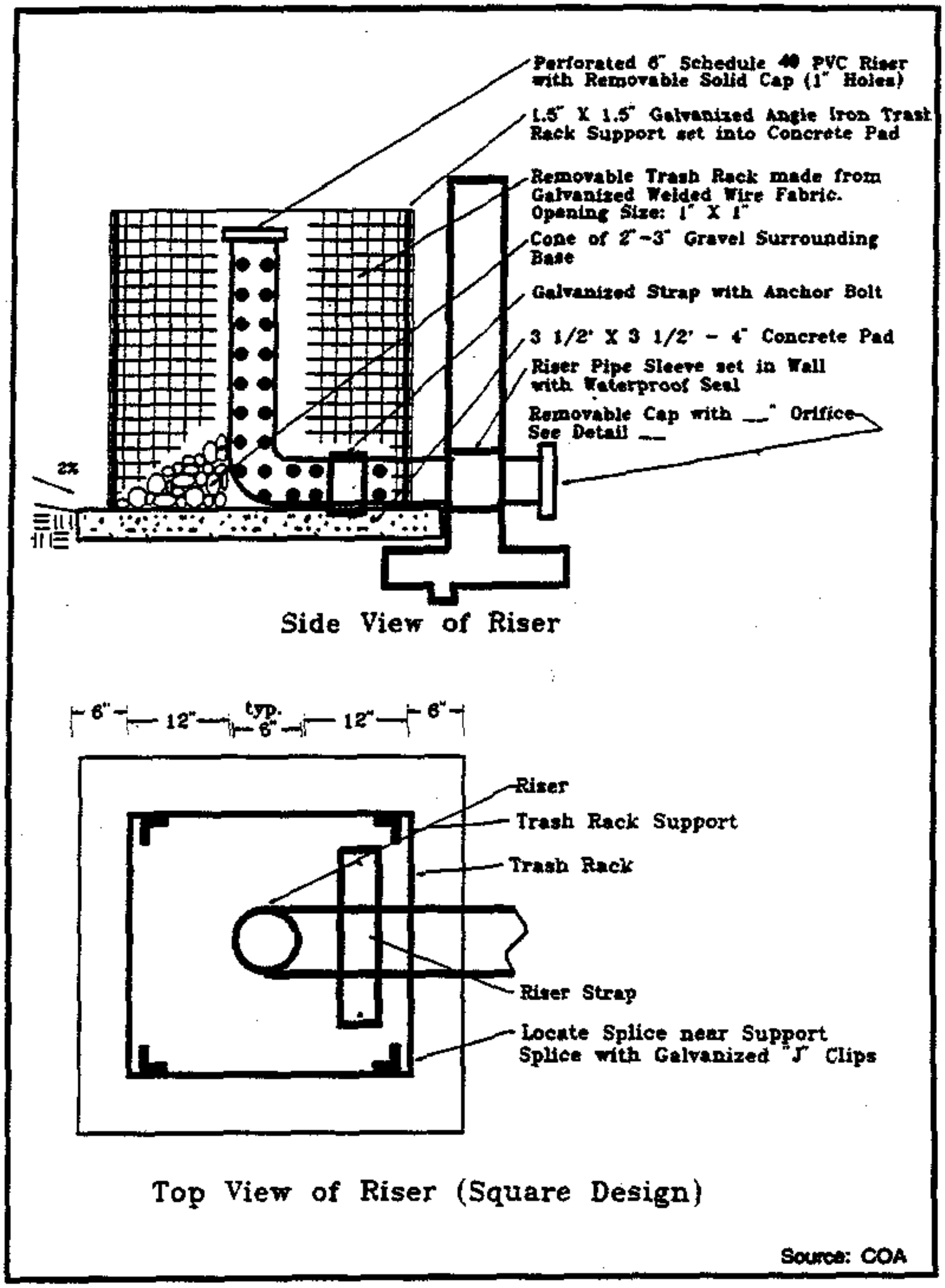

Figure 4.5 Detail of Sedimentation Riser Pipe

(12) *Safety Considerations* - Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate dropoffs and other hazards. Earthen sideslopes should not exceed 3:1 (H:V) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. The primary spillway opening must not permit

access by small children. Outfall pipes above 48 inches in diameter should be fenced.

(13) *Landscaping Plan* - A landscaping plan shall be provided indicating how adjacent terrestrial areas will be stabilized.

4.8 Wet Basins

Wet basins are stormwater quality control facilities that maintain a permanent wet pool and a standing crop of emergent littoral vegetation. These facilities may vary in appearance from natural ponds to enlarged, bermed (manmade) sections of drainage systems and may function as online or offline facilities, although offline configuration is preferable. Offline designs can prevent scour and other damage to the wet pond and minimize costly outflow structure elements needed to accommodate extreme runoff events.

During storm events, runoff inflows displace part or all of the existing basin volume and are retained and treated in the facility until the next storm event. The pollutant removal mechanisms are settling of solids, wetland plant uptake, and microbial degradation. When the wet basin is adequately sized, pollutant removal performance can be excellent, especially for the dissolved fraction. Wet basins also help provide erosion protection for the receiving channel by limiting peak flows during larger storm events.

Wet basins are often perceived as a positive aesthetic element in a community and offer significant opportunity for creative pond configuration and landscape design. Participation of an experienced wetlands designer is suggested. A significant potential drawback for wet ponds in the central Texas area is that the contributing watershed for these facilities is often incapable of providing an adequate water supply to maintain the permanent pool, especially during the summer months. Treated water is sometimes used to supplement the rainfall/runoff process, especially for wet basin facilities treating smaller, more densely developed watersheds (LCRA, 1998).

Design Criteria

(1) *Facility Sizing* – The basin should be sized to hold the permanent pool as well as the required water quality volume. The water quality volume should be calculated as described in Section 3.0. This volume should be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. The volume of the permanent pool should be twice the water quality volume.

(2) *Pond Configuration* - The wet basin should be configured as a two stage facility with a sediment forebay and a main pool. The basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. The minimum length to width ratio should be 1.0. Higher ratios are recommended. The perimeter of all permanent pool areas with depths of 4.0 feet or greater shall be surrounded by two benches. A flat (no steeper than 3 percent) safety bench at least 10 feet wide shall be provided adjacent to the boundary of the maximum pool elevation. An aquatic

bench extending inward at least 10 feet wide from the perimeter of the permanent pool and no more than 18 inches below normal depth shall also be provided.

(3) *Pond Sideslopes* - Side slopes of the basin should be 3:1 or flatter for grass stabilized slopes. Slopes steeper than 3:1 should be stabilized with an appropriate slope stabilization practice.

(4) *Sediment Forebay* - A sediment forebay is required to isolate gross sediments as they enter the facility and to simplify sediment removal. The sediment forebay should consist of a separate cell formed by an earthen berm, gabion, or loose riprap wall. The forebay should be sized to contain 15 to 25% of the permanent pool volume and should be at least 3 feet deep. Exit velocities from the forebay should not be erosive. Direct maintenance access should be provided to the forebay. The bottom of the forebay may be hardened to make sediment removal easier. A fixed vertical sediment depth marker should be installed in the forebay to measure sediment accumulation.

(5) *Outflow Structure* - The low flow orifice should have a minimum diameter of 4 inches and shall be sized to define the facility drawdown time. Figure 4.6 presents a schematic representation of acceptable outflow structures. The facility should have a separate drain pipe with a manual valve that can completely or partially drain the pond for maintenance purposes. To allow for possible sediment accumulation, the submerged end of the pipe should be protected, and the drain pipe should be sized one pipe schedule higher than the calculated diameter needed to drain the pond within 24 hours. The valve should be located at a point where it can be operated in a safe and convenient manner.

For online facilities, the principal and emergency spillways must be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the 100-year flood. The embankment should be designed in accordance with all relevant specifications for small dams.

(6) *Splitter Box* - When the pond is designed as an offline facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year event while providing at least 1.0 foot of freeboard along pond sideslopes.

(7) *Vegetation* - A plan should be prepared that indicates how aquatic and terrestrial areas will be vegetatively stabilized. Wetlands vegetation elements should be placed along the aquatic bench or in the shallow portions of the permanent pool. The optimal elevation for planting of wetlands vegetation is within 6 inches vertically of the normal pool elevation. Design guidance for vegetation is provided in "Design of Stormwater Wetlands Systems" (Schueler, 1992).

A pond buffer should be provided that extends 25 feet outward from the maximum water surface elevation of the pond. Trees in the buffer area should be preserved during construction. Trees, shrubs, and native ground cover should be planted in the buffer area if they do not presently exist. The only mowing required within the buffer area is along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow.

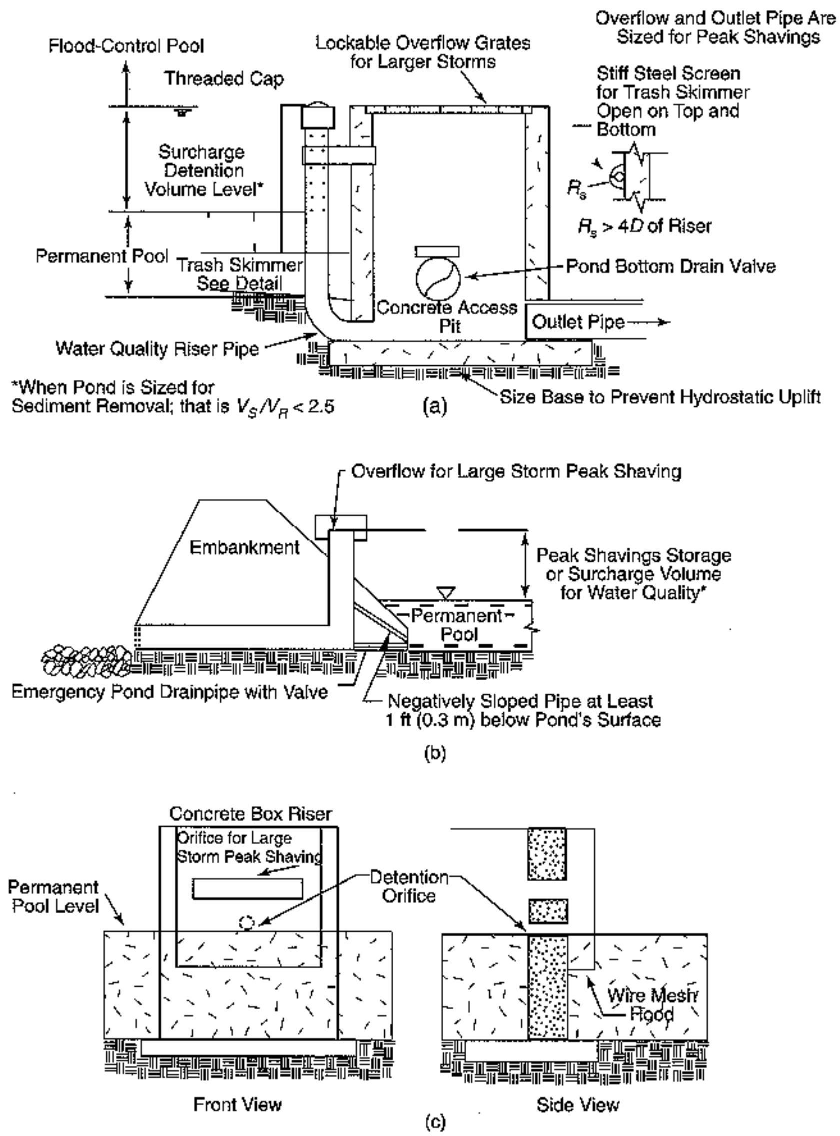

Figure 4.6 Schematic Diagrams of Wet Basin Outlets (WEF and ASCE, 1998)

(8) *Erosion Protection at the Outfall* - For online facilities, special consideration should be given to the facility’s outfall location. Flared pipe end sections that discharge at or near the stream invert are preferred. The

channel immediately below the pond outfall shall be modified to conform to natural dimensions, and lined with large riprap placed over filter cloth. A stilling basin should be used to reduce flow velocities from the primary spillway to non-erosive velocities.

(9) *Safety Considerations* - Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate dropoffs and other hazards. Earthen sideslopes should not exceed 3:1 (h:v) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. The primary spillway opening should not permit access by small children. Outfall pipes above 48 inches in diameter should be fenced.

(10) *Depth of the Permanent Pool* - The permanent pool should be no deeper than 8 feet and should average 4-6 feet deep.

(11) *Embankment* - At least 10 percent extra fill should be placed on the embankment to account for possible settling.

4.9 Constructed Wetland

Constructed wetlands are shallow pools with or without open water elements that create growing conditions suitable for marsh plants. Conventional stormwater wetlands are shallow manmade facilities supporting abundant vegetation and a robust microbial population. These facilities are generally designed as offline BMPs, but may be situated online if flows from extreme events can be accommodated without damage to the facility. Wetlands facilities are designed to maximize pollutant removal through plant uptake, microbial degradation, and settling of solids. As constructed water quality facilities, stormwater wetlands should never be located within delineated natural wetlands areas. In addition, they differ from manmade wetlands used to comply with mitigation requirements in that they do not replicate all of the ecological functions of a natural wetland (LCRA, 1998).

Like wet basins, constructed wetlands are capable of excellent pollutant removal if sized and designed properly. Performance is generally good with respect to settling of the solids fraction and for the dissolved constituents as well due to active microbial action. Enhanced design elements include a sediment forebay, micropool areas, a complex microtopography, pondscaping, and multiple species of wetlands trees, shrubs and plants. Significant potential exists for creative design and participation of an experienced wetlands designer is highly recommended. As with wet basins, a consistent source of water is necessary to sustain the system; thus, in smaller and urban applications, treated water may be required to supplement natural sources. Maintenance requirements are most intensive during the early stages when the wetlands is being established (LCRA, 1998).

<u>Design Criteria (LCRA, 1998)</u>

(1) *Facility Sizing* – The water quality volume requirements are presented in Section 3 of this manual. This volume shall be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities.

(2) *Pond Configuration* - Stormwater constructed wetlands offer significant flexibility regarding pond configuration with the exception that short-circuiting of the facility must be avoided. Provision of irregular, multiple flow paths is desired. The use of open water elements (micropools) is recommended, especially near the facility outlet, both as a means of diversifying the biological community and as an aesthetic consideration. Islands may be placed in the facility to enhance waterfowl habitat and placement of trees. A flat area at least 10-feet wide (safety bench) must exist along the perimeter of the facility. At least 25 percent of the pond perimeter must be planted with open grass. Ideally, a 30-foot landscaped buffer should surround the entire facility.

(3) *Sediment Forebay* - A sediment forebay is required to isolate gross

sediments as they enter the facility and to simplify sediment removal. The sediment forebay should consist of a separate cell formed by an earthen berm, gabion wall, or loose riprap wall. The forebay shall be sized to contain 0.25 inches per impervious acre of contributing drainage area and shall be 2-4 feet deep. Direct maintenance access should be provided to the forebay. A fixed vertical sediment depth marker should be installed in the forebay to mark sediment accumulation.

(4) *Vegetation* - A diverse, locally appropriate selection of plant species is vital for all constructed wetlands. A planting plan should be prepared that indicates number of plants from each species to be used and how aquatic and terrestrial areas will be vegetatively stabilized. Design guidelines for wetlands vegetation are provided in, "Design of Stormwater Wetlands Systems" (Schueler, 1992) and other publications. Participation of a wetlands designer or landscape architect familiar with local plants is highly recommended.

(5) *Outflow Structure* - The low flow orifice should have a minimum diameter of 4 inches and shall be sized to define the facility drawdown time. The facility shall have a separate drain pipe with a manual valve that can completely or partially drain the pond for maintenance purposes. To allow for possible sediment accumulation, the submerged end of the pipe should be protected, and the drain pipe should be sized one pipe schedule higher than the calculated diameter needed to drain the pond within 24 hours. The valve shall be located at a point where it can be operated in a safe and convenient manner. For online facilities, the principal and emergency spillways should be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the 100-year flood. The embankment should be designed in accordance with all relevant state and federal specifications for small dams.

(6) *Depth of Inundation During Storm Events* - The depth of inundation of the facility above the normal pool elevation should not exceed 2.0 feet during the 25-year event.

(7) *Offline Configuration* - Offline configuration of the facility is required except where the designer can demonstrate that extreme events will not encourage scour or other damage to the wetlands. When the wetland is designed as an offline facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, shall be designed to convey the 25-year event while providing at least 0.5 foot of freeboard along the wetland sideslopes.

(8) *Depth of Micropools* - The depth of micropools should not exceed 4 feet.

(9) *Observation Well* - Constructed wetlands shall have an observation well installed to monitor performance. The wells may be a securely anchored

vertical perforated PVC pipe, 4-6” in diameter, or other acceptable device designed to permit observation of water and sediment levels.

5 Innovative Technology: Use and Evaluation

The development and use of innovative, cost-effective stormwater management technologies are encouraged. Implementation of BMPs not discussed must be approved by the Executive Director. Approval will be contingent on submission of objective, verifiable data that supports the claimed TSS removal efficiency. If such data does not exist, a single site may be approved subject to the constraint that a monitoring program will be initiated in the first year of operation to document the TSS removal of the device or measure.

The application to implement an innovative BMP must include these additional elements:

(1) Documentation of mechanism(s) by which the TSS will be reduced.

(2) Documentation and/or discussion of potential causes of poor performance or failure of the BMP.

(3) Key design specifications or considerations.

(4) Specific installation requirements.

(5) Specific maintenance requirements.

(6) Data to support the claimed TSS removal efficiency.

(7) If the technology is new or the existing data is not considered reliable, a detailed monitoring plan to assess the TSS removal may be required.

Criteria that will be used to judge the adequacy of existing monitoring data or a proposed BMP monitoring plan include:

(1) Flow weighted composite samples are collected and used to determine the TSS concentrations in the influent and effluent of the device.

(2) The performance of the BMP is based on the sampling results from at least ten storms. These storms should be representative of those normally occurring in the area.

(3) The samples are collected and handled according to established QA/QC procedures that are included in the plan.

(4) The laboratory selected for analysis of the samples is recognized as technically proficient.

(5) The efficiency of the device is calculated based on the total TSS load removed for all monitored storm events.

6 Maintenance Requirements

6.1 Maintenance Plan

A maintenance plan developed by the design engineer and acceptable to TNRCC will be required prior to issuance of the construction permit. The following information should be included in the proposed maintenance plan.

(1) Specification of routine and nonroutine maintenance activities to be performed;

(2) A schedule for maintenance activities;

(3) Provision for access to the tract by TNRCC or other designated inspectors; and,

(4) Name, qualifications and contact information for the party(ies) responsible for maintaining the BMP(s).

6.2 General Guidelines

The ability and the commitment to maintain stormwater management facilities are necessary for the proper operation of these facilities. The designer must consider the maintenance needs and the type of maintenance that will take place, in order to provide for adequate access to and within the facility site.

To help stormwater management planners, designers, and reviewers include system maintenance, specific maintenance considerations were developed by Livingston et al (1997). These considerations, which were originally developed for the New Jersey Department of Environmental Protection's Stormwater Management Facility Maintenance Manual, should be considered whenever a stormwater management practice is pondered, planned, designed, or reviewed. The facility designer should pretend that they must do the maintenance to see if access and maintainability are provided.

6.2.1 Maintainability

Maintainability can be expressed in three ways, all of which should be given equal importance by facility designers and reviewers:

- Every effort should be made to minimize the amount and frequency of regular maintenance at a stormwater management system.

- Performance of the remaining maintenance tasks should be as easy to perform as possible.

- All efforts should be made to eliminate the need for emergency or extraordinary maintenance at the facility.

Recommended techniques for accomplishing these goals, which can be used to both select the most appropriate type of BMP, as well as design and review it, are presented below.

6.2.2 Accessibility

According to many maintenance personnel, the biggest problem they encounter is not the amount or frequency of maintenance they must perform, but the difficulties they have in simply reaching the location of the required maintenance work. In order for proper maintenance to be performed, the various components of the stormwater system and, indeed, the facility itself, must be accessible to both maintenance personnel and their equipment and materials. Physical barriers such as fences, curbs, steep slopes, and lack of adequate and stable walking, standing, climbing, and staging areas can seriously hinder maintenance efforts and drastically increase maintenance difficulty, cost, time, and safety hazards. Amenities such as depressed curbs, hand and safety rails, gates, access roads, hatches, and manholes will expedite both inspection and maintenance efforts and help hold down costs and improve efficiency.

Important design considerations for components such as gates, hatches, manholes, trash racks, and other components that must be lifted or moved during inspection or maintenance operations, include both the item's weight and a secure place to put it when it's not in its normal location. When weight becomes excessive, mechanical aids such as hoists, lifts, and lifting hooks should be provided. When fastening removable items like trash racks, orifice and weir plates, and gratings, the use of noncorroding, removable, and readily accessible fasteners will also help greatly.

Sometimes design considerations may conflict. For example, in designing access roads, they must have the proper turning radius, slope, and wheel loading to allow cleaning of a pond by heavy construction equipment. The road's storm drain covers, designed for the desired wheel loading, may be too heavy to move easily. Perhaps a different access way may need to be provided.

Finally, legal barriers such as lack of access rights or inadequate maintenance easements can stop the best maintenance efforts before they can even get started. This is especially pertinent to project reviewers, who normally have the authority to require such legal aspects of the project.

6.2.3 Durability

The use of strong, durable, and non-corroding materials, components, and fasteners can greatly expedite facility maintenance efforts. These include strong, lightweight metals such as aluminum for trash racks, orifice and weir plates, and access hatches; reinforced concrete for outlet structures and inlet headwalls; hardy, disease resistant vegetation for bottoms, side slopes, and perimeters; and durable rock for gabions and riprap linings. In most instances, the extra investment normally required for more durable materials will pay off over time**.**

6.2.4 Material Disposal

Stormwater pollutants include a variety of substances that are deposited on pervious and impervious surfaces and then transported by the next rainfall. In addition, there may be connections to the stormwater system that should go to the sanitary sewer system in older urbanized areas. Consequently, a variety of contaminants that may be classified as hazardous or toxic may enter stormwater management systems. These contaminants include heavy metals, petroleum hydrocarbons, pesticides, and a variety of organic chemicals. Consequently, several federal and state laws and regulations may apply to the disposal of sediments which accumulate in stormwater systems or which are captured by street sweepers (Livingston et al, 1997).

Sediment and other materials that accumulate in stormwater BMPs must be disposed of properly. The following is a basic description of the steps required for solid waste disposal:

1) The waste must be characterized.

2) Based on the characterization, the waste must be classified.

3) Based on the classification, the waste must be disposed of properly according to current state (30 TAC 330 or 335) and federal rules (40 CFR Subchapter C or D).

The sediment must be determined to be inert for on-site disposal. Under certain conditions the sediment can be disposed of in a dumpster, but only after the above steps are completed, and the waste is found to have an acceptable classification for this type of disposal.

It is common for a generator of certain types of solid waste to characterize and classify a waste based on industry knowledge. For example, making a comparison of test results from similar facilities. Sediment from stormwater BMPs has been collected and analyzed from numerous sites in the U.S. and Texas, and, in general, the sediment was not classified as hazardous. These tests indicate that disposal in municipal landfills is often the appropriate method of disposal. Nevertheless, the individual generator is still responsible for proper classification and disposal of the accumulated sediment.

6.3 Retention/Irrigation

The following guidelines should be used to develop the maintenance plan for the retention/irrigation BMP.

- *Inspections*. The irrigation system should be inspected and tested (or observed while in operation) to assure proper operation at least 6 times annually. Two of these inspections should occur during or immediately following wet weather. Any leaks, broken spray heads, or other malfunctions with the irrigation system should be repaired immediately.

- *Sediment Removal.* Remove sediment from inlet structure/sediment forebay, and from around the sump area at least 2 times annually, or when depth reaches 3 inches. When the accumulated sediment reaches a depth of 6 inches in other areas of the basin, all accumulated sediment should be removed and disposed of properly.

- *Mowing.* The upper stage, side slopes, and embankment of a retention basin must be mowed regularly to discourage woody growth and control weeds. Grass areas in and around basins must be mowed at least twice annually to limit vegetation height to 18 inches. More frequent mowing to maintain aesthetic appeal may be necessary in landscaped areas. When mowing is performed, a mulching mower should be used, or grass clippings should be caught and removed.

- *Debris and Litter Removal.* Debris and litter will accumulate near the basin pump and should be removed during regular mowing operations and inspections. Particular attention should be paid to floating debris that can eventually clog the irrigation system.

- *Erosion Control.* The pond side-slopes and embankment may periodically suffer from slumping and erosion, although this should not occur often if the soils are properly compacted during construction. Regrading and revegetation may be required to correct the problems.

- *Nuisance Control.* Standing water or soggy conditions in the retention basin can create nuisance conditions for nearby residents. Odors, mosquitos, weeds, and litter are all occasionally perceived to be problems. Most of these problems are generally a sign that regular inspections and maintenance are not being performed (e.g., mowing and debris removal).

6.4 Extended Detention Basins

Extended detention basins have moderate to high maintenance requirements, depending on the extent to which future maintenance needs are anticipated during the design stage. Responsibilities for both routine and nonroutine maintenance tasks need to be clearly understood and enforced. If regular maintenance and inspections are not undertaken, the pond will not achieve its intended purposes.

There are many factors that may affect the basin's operation and that should be periodically checked. These factors can include mowing, control of pond vegetation, removal of accumulated bottom sediments, removal of debris from all inflow and outflow structures, unclogging of orifice perforations, and the upkeep of all physical structures that are within the detention pond area. One should conduct periodic inspections and after each significant storm. Remove floatables and correct erosion problems in the pond slopes and bottom. Pay particular attention to the outlet control perforations for signs of clogging. If the orifices are clogged, remove sediments. The generic aspects that must be considered in the maintenance plan for a detention facility are as follows:

- *Inspections.* Basins should be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. When possible, inspections should be conducted during wet weather to determine if the pond is meeting the target detention times. In particular, the extended detention control device should be regularly inspected for evidence of clogging, or conversely, for too rapid a release. If the design drawdown times are exceeded by more than 24 hours, then repairs should be scheduled immediately. The upper stage pilot channel, if any, and its flow path to the lower stage should be checked for erosion problems. During each inspection, erosion areas inside and downstream of the BMP should be identified and repaired or revegetated immediately

- *Mowing.* The upper stage, side slopes, embankment, and emergency spillway of an extended detention basin must be mowed regularly to discourage woody growth and control weeds. Grass areas in and around basins should be mowed at least twice annually to limit vegetation height to 18 inches. More frequent mowing to maintain aesthetic appeal may be necessary in landscaped areas. When mowing of grass is performed, a mulching mower should be used, or grass clippings should be caught and removed.

- *Debris and Litter Removal.* Debris and litter will accumulate near the extended detention control device and should be removed during regular mowing operations and inspections. Particular attention should be paid to floating debris that can eventually clog the control device or riser.

- *Erosion Control.* The pond side-slopes, emergency spillway, and embankment all may periodically suffer from slumping and erosion, although this should not occur often if the soils are properly compacted during construction. Regrading and revegetation may be required to correct the problems. Similarly, the channel connecting an upper stage with a lower stage may periodically need to be replaced or repaired.

- *Structural Repairs and Replacement.* With each inspection, any damage to the structural elements of the system (pipes, concrete drainage structures, retaining walls, etc.) should be identified and repaired immediately. The various inlet/outlet and riser works in a basin will eventually deteriorate and must be replaced. Public works experts have estimated that corrugated metal pipe (CMP) has a useful life of about 25 yr, whereas reinforced concrete barrels and risers may last from 50 to 75 yr.

- *Nuisance Control.* Standing water (not desired in a extended detention basin) or soggy conditions within the lower stage of the basin can create nuisance conditions for nearby residents. Odors, mosquitos, weeds, and litter are all occasionally perceived to be problems. Most of these problems are generally a sign that regular inspections and maintenance are not being performed (e.g., mowing, debris removal, clearing the outlet control device).

- *Sediment Removal.* When properly designed, dry extended detention basins will accumulate quantities of sediment over time. Sediment accumulation is a serious maintenance concern in extended detention dry ponds for several reasons. First, the sediment gradually reduces available stormwater management storage capacity within the basin. Second, unlike wet extended detention basins (which have a permanent pool to conceal deposited sediments), sediment accumulation can make dry extended detention basins very unsightly. Third, and perhaps most importantly, sediment tends to accumulate around the control device. Sediment deposition increases the risk that the orifice will become clogged, and gradually reduces storage capacity reserved for pollutant removal. Sediments can also be resuspended if allowed to accumulate over time and escape through the hydraulic control to downstream channels and streams. For these reasons, accumulated sediment needs to be removed from the lower stage when sediment buildup exceeds 6 inches or when the proper functioning of inlet and outlet structures is impaired. Sediment should be cleared from the sedimentation chamber at least every 10 years.

6.5 Grassy Swales

Maintenance for grassed swales is minimal and is largely aimed at keeping the grass cover dense and vigorous. Maintenance practices and schedules should be developed and included as part of the original plans to alleviate maintenance problems in the future. Recommended practices include (modified from Young et al, 1996):

- *Seasonal Mowing and Lawn Care*. Lawn mowing should be performed routinely, as needed, throughout the growing season. Grass height should be maintained at 2 inches above the design water depth. Grass cuttings should be collected and disposed offsite, or a mulching mower can be used. Regular mowing should also include weed control practices; however, herbicide use should be kept to a minimum (Urbonas, 1992). Healthy grass can be maintained without using fertilizers because runoff usually contains sufficient nutrients.

- *Inspection*. Inspect swales at least twice annually for erosion or damage to vegetation; however, additional inspection after periods of heavy runoff is most desirable. The swale should be checked for uniformity of grass cover, debris and litter, and areas of sediment accumulation. More frequent inspections of the grass cover during the first few years after establishment will help to determine if any problems are developing, and to plan for long-term restorative maintenance needs. Bare spots and areas of erosion identified during semi-annual inspections must be replanted and restored to meet specifications. Construction of a level spreader device may be necessary to reestablish shallow overland flow.

- *Debris and Litter Removal*. Trash tends to accumulate in swale areas, particularly along highways. Any swale structures (i.e. check dams) should be kept free of obstructions to reduce floatables being flushed downstream, and for aesthetic reasons. The need for this practice is determined through periodic inspection, but should be performed no less than two times per year (Urbonas, 1992).

- *Sediment Removal*. Sediment accumulating near culverts and in channels needs to be removed when they build up to 3 in at any spot, or cover vegetation. Excess sediment should be removed by hand or with flat-bottomed shovels. If areas are eroded, they should be filled, compacted, and reseeded so that the final grade is level with the bottom of the swale. Sediment removal should be performed periodically, as determined through inspection. Depending on the type of pollutants accumulated, some sediments may be considered hazardous waste or toxic material, and are therefore subject to restrictions for disposal.

- *Grass Reseeding and Mulching*. A healthy dense grass should be maintained in the channel and side slopes. Grass damaged during the sediment removal process should be promptly replaced using the same seed mix used during swale establishment. If possible, flow should be diverted from the damaged areas until the grass is firmly established.

- *Public Education*. Private homeowners are often responsible for roadside swale maintenance. Unfortunately, overzealous lawn care on the part of homeowners can present some problems. For example, mowing the swale too close to the ground, or excessive application of fertilizer and pesticides will all be detrimental to the performance of the swale. Pet waste can also be a problem in swales, and should be removed to avoid contamination from fecal coliform and other waste-associated bacteria. The delegation of maintenance responsibilities to individual landowners is a cost benefit to the locality. However, localities should provide an active educational program to encourage the recommended practices.

6.6 Vegetative Filter Strips

Once a vegetated area is well established, little additional maintenance is generally necessary. The key to establishing a viable vegetated feature is the care and maintenance it receives in the first few months after it is planted. Once established, all vegetated BMPs require some basic maintenance to insure the health of the plants including:

- *Seasonal Mowing and Lawn Care*. If the filter strip is made up of turf grass, it should be mowed as needed to limit vegetation height to 4", using a mulching mower (or removal of clippings). If native grasses are used, the filter may require less frequent mowing, but a minimum of twice annually. Grass clippings and brush debris should not be deposited on vegetated filter strip areas. Regular mowing should also include weed control practices, however herbicide use should be kept to a minimum (Urbonas, 1992). Healthy grass can be maintained without using fertilizers because runoff usually contains sufficient nutrients. Irrigation of the site can help assure a dense and healthy vegetative cover.

- *Inspection*. Inspect filter strips at least twice annually for erosion or damage to vegetation; however, additional inspection after periods of heavy runoff is most desirable. The strip should be checked for uniformity of grass cover, debris and litter, and areas of sediment accumulation. More frequent inspections of the grass cover during the first few years after establishment will help to determine if any problems are developing, and to plan for long-term restorative maintenance needs. Bare spots and areas of erosion identified during semi-annual inspections must be replanted and restored to meet specifications. Construction of a level spreader device may be necessary to reestablish shallow overland flow.

- *Debris and Litter Removal*. Trash tends to accumulate in vegetated areas, particularly along highways. Any filter strip structures (i.e. level spreaders) should be kept free of obstructions to reduce floatables being flushed downstream, and for aesthetic reasons. The need for this practice is determined through periodic inspection, but should be performed no less than 4 times per year.

- *Sediment Removal*. Sediment removal is not normally required in filter strips, since the vegetation normally grows through it and binds it to the soil. However, sediment may accumulate along the upstream boundary of the strip preventing uniform overland flow. Excess sediment should be removed by hand or with flat-bottomed shovels. Depending on the type of pollutants accumulated, some sediments may be considered hazardous waste or toxic material, and are therefore subject to restrictions for disposal.

- *Grass Reseeding and Mulching*. A healthy dense grass should be maintained on the filter strip. If areas are eroded, they should be filled, compacted, and reseeded so that the final grade is level. Grass damaged during the sediment removal process should be promptly replaced using the same seed mix used during filter strip establishment. If possible, flow should be diverted from the damaged areas until the grass is firmly established. Bare spots and areas of erosion identified during semi-annual inspections must be replanted and restored to meet specifications. Corrective maintenance, such as weeding or replanting should be done more frequently in the first two to three years after installation to ensure stabilization. Dense vegetation may require irrigation immediately after planting, and during particularly dry periods, particularly as the vegetation is initially established.

6.7 Sand Filter Systems

Intermittent sand filters require a high degree of maintenance compared to other BMPs. Regular, routine maintenance is essential to effective, long-lasting performance. Neglect or failure to service the filters on a regular basis will lead to poor performance and eventual costly repairs. It is recommended that sand filter BMPs be inspected on a quarterly basis and after large storms for the first year of operation. This intensive monitoring is intended to ensure proper operation and provide maintenance personnel with a feel for the operational characteristics of the filter. Subsequent inspections can be limited to semi-annually or more often if deemed necessary (Young et al, 1996).

Certain construction and maintenance practices are essential to efficient operation of the filter. The biggest threat to any filtering system is exposure to heavy sediment loads that clog the filter media. Construction within the watershed should be complete prior to exposing the filter to stormwater runoff. All exposed areas should be stabilized to minimize sediment loads. Runoff from any unstabilized construction areas should be treated via a separate sediment system that bypasses the filter media.

Another important consideration in constructing the filter bed, is to ensure that the top of the media is completely level. The filter design is based on the use of the entire filter media surface area; a sloped filter surface would result in disproportionate use of the filter media.

Other recommended maintenance guidelines include:

- *Inspections.* BMP facilities must be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. During each inspection, erosion areas inside and downstream of the BMP must be identified and repaired or revegetated immediately. With each inspection, any damage to the structural elements of the system (pipes, concrete drainage structures, retaining walls, etc.) must be identified and repaired immediately.

- *Sediment Removal*. Remove sediment from the inlet structure and sedimentation chamber when sediment buildup reaches 6 inches or when the proper functioning of inlet and outlet structures is impaired. Sediment must be cleared from the inlet structure at least every year, and from the sedimentation basin at least every 5 years. Silt accumulated on the surface of the filter media should be removed when it has reached a depth of about 0.5 inch or the drainage time has increased to more than 48 hours.

- *Media Replacement*. More extensive maintenance of the filter media is required when the draw-down time begins to exceed the target time of 48 hours. Non-routine maintenance or corrective maintenance should be performed when the draw-down time exceeds 72 hours. When this occurs, the upper layer of geotechnical material and gravel ballast should be removed and replaced with new materials meeting the original specifications. Any discolored sand should also be removed and replaced. In filters that have been regularly maintained, this should be limited within the top 2 to 3 inches.

- *Debris and Litter Removal.* Debris and litter will accumulate near the sedimentation basin outlet device and should be removed during regular mowing operations and inspections. Particular attention should be paid to floating debris that can eventually clog the control device or riser.

- *Filter Underdrain.* Clean underdrain piping network to remove any sediment buildup every 2 years, or as needed to maintain design drawdown time.

- *Mowing.* Grass areas in and around sand filters must be mowed at least twice annually to limit vegetation height to 18 inches. More frequent mowing to maintain aesthetic appeal may be necessary in landscaped areas.

6.8 Wet Basins

A clear requirement for wet basins is that a firm commitment be made to carry out both routine and non-routine maintenance tasks. The nature of the maintenance requirements are outlined below, along with design tips that can help to reduce the maintenance burden (modified from Young et al, 1996).

<u>Routine Maintenance</u>.

- *Mowing.* The side-slopes, embankment, and emergency spillway of the basin should be mowed at least twice a year to prevent woody growth and control weeds.

- *Inspections.* Wet basins should be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. When possible, inspections should be conducted during wet weather to determine if the basin is functioning properly. There are many functions and characteristics of these BMPs that should be inspected. The embankment should be checked for subsidence, erosion, leakage, cracking, and tree growth. The condition of the emergency spillway should be checked. The inlet, barrel, and outlet should be inspected for clogging. The adequacy of upstream and downstream channel erosion protection measures should be checked. Stability of the sideslopes should be checked. Modifications to the basin structure and contributing watershed should be evaluated. During semi-annual inspections, replace any dead or displaced vegetation. Replanting of various species of wetland vegetation may be required at first, until a viable mix of species is established. The inspections should be carried out with as-built pond plans in hand.

- *Debris and Litter Removal.* As part of periodic mowing operations and inspections, debris and litter should be removed from the surface of the basin. Particular attention should be paid to floatable debris around the riser, and the outlet should be checked for possible clogging.

- *Erosion Control.* The basin side-slopes, emergency spillway, and embankment all may periodically suffer from slumping and erosion. Corrective measures such as regrading and revegetation may be necessary. Similarly, the riprap protecting the channel near the outlet may need to be repaired or replaced.

- *Nuisance Control.* Most public agencies surveyed indicate that control of insects, weeds, odors, and algae may be needed in some ponds. Nuisance control is probably the most frequent maintenance item demanded by local residents. If the ponds are properly sized and vegetated, these problems should be rare in wet ponds except under extremely dry weather conditions. Twice a year, the facility should be evaluated in terms of nuisance control (insects, weeds, odors, algae, etc.). Biological control of algae and mosquitos using fish such as fathead minnows is preferable to chemical applications.

Non-routine maintenance.

- *Structural Repairs and Replacement.* Eventually, the various inlet/outlet and riser works in the wet basin will deteriorate and must be replaced. Some public works experts have estimated that corrugated metal pipe (CMP) has a useful life of about 25 yr, while concrete barrels and risers may last from 50 to 75 yr. The actual life depends on the type of soil, pH of runoff, and other factors. Polyvinyl chloride (PVC) pipe is a corrosion resistant alternative to metal and concrete pipes. Local experience typically determines which materials are best suited to the site conditions. Leakage or seepage of water through the embankment can be avoided if the embankment has been constructed of impermeable material, has been compacted, and if anti-seep collars are used around the barrel. Correction of any of these design flaws is difficult.

- *Sediment Removal.* Wet ponds will eventually accumulate enough sediment to significantly reduce storage capacity of the permanent pool. As might be expected, the accumulated sediment can reduce both the appearance and pollutant removal performance of the pond. Sediment accumulated in the sediment forebay area must be removed from the facility every two years or when accumulations exceed 6 inches. Dredging of the permanent pool must occur when the storage volume is reduced by greater than 15 percent or when accumulation of sediment impairs functioning of the outlet structure. Dredging of the permanent pool must occur at least every 10 years.

- *Harvesting* If vegetation is present on the fringes or in the pond, it should be periodically harvested and the clippings removed to provide export of nutrients and to prevent the basin from filling with decaying organic matter.

6.9 Constructed Wetland

Constructed wetlands, like wet basins, require a firm commitment be made to carry out both routine and non-routine maintenance tasks. The nature of the maintenance requirements are outlined below(modified from Young et al, 1996).

Routine Maintenance.

- *Mowing.* The side-slopes, embankment, and emergency spillway of a wetland must be mowed at least twice a year to control weeds.

- *Inspections.* Wetlands shouls be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. When possible, inspections should be conducted during wet weather to determine if the BMP is functioning properly. There are many functions and characteristics of wetlands that should be inspected. The embankment should be checked for subsidence, erosion, leakage, cracking, and tree growth. The condition of the emergency spillway should be checked. The inlet and outlet should be inspected for clogging. The adequacy of upstream and downstream channel erosion protection measures should be checked. Stability of the sideslopes should be checked. During semi-annual inspections, replace any dead or displaced vegetation. Replanting of various species of wetland vegetation may be required at first, until a viable mix of species is established. During semi-annual inspections, the water level should be checked in the monitoring well. At least one of the inspections should occur during the summer. If insufficient water levels are found, supplemental water should be supplied, and the well rechecked monthly during the dry season.

- *Debris and Litter Removal.* As part of periodic mowing operations and inspections, debris and litter should be removed from the wetland to prevent clogging of any outlet. Also, the wetland will be more aesthetically pleasing if trash and debris are removed on a regular basis (Urbonas, 1992).

- *Erosion Control.* The wetland side-slopes, emergency spillway, and embankment all may periodically suffer from slumping and erosion. Corrective measures such as regrading and revegetation may be necessary. Similarly, the riprap protecting the channel near the outlet may need to be repaired or replaced.

- *Nuisance Control.* Most public agencies surveyed indicate that control of insects, weeds, odors, and algae may be needed in some wetlands. Nuisance control is probably the most frequent maintenance item demanded by local residents. Twice a year, the facility should be evaluated in terms of nuisance control (insects, weeds, odors, algae, etc.). Biological control of algae and mosquitos using fish such as fathead minnows is preferable to chemical applications. This is extremely important with wetlands, as pesticides are likely to adversely affect the microorganisms that are responsible for much of the pollutant removal.

Non-routine maintenance.

- *Structural Repairs and Replacement.* Eventually, the various inlet/outlet and riser works in a wetland will deteriorate and must be replaced. Some public works experts have estimated that corrugated metal pipe (CMP) has a useful life of about 25 yr, while concrete barrels and risers may last from 50 to 75 yr. The actual life depends on the type of soil, pH of runoff, and other factors. Polyvinyl chloride (PVC) pipe is a corrosion resistant alternative to metal and concrete pipes. Leakage or seepage of water through the embankment can be avoided if the embankment has been constructed of impermeable material, has been compacted, and if anti-seep collars are used around the barrel. Correction of any of these design flaws is difficult.

- *Sediment Removal.* During semi-annual inspections, sediment must be removed from the inlet structure/sediment forebay, or when sediment depth reaches 3”, or when sediment interferes with the health of the vegetative community. Accumulated sediment and muck in the remainder of the wetland should be removed every 5 to 15 yr, or as needed based on inspection. The growth zone depths and spatial distribution should be maintained (Urbonas, 1992).

- *Harvesting* Cattails, reeds and other plants should be harvested to permanently remove nutrients from the wetland area. Plants may be harvested manually or mechanically, depending on the wetland area. Harvesting should be conducted every five years at a minimum.

  Harvesting is generally not effective in removing chemicals, such as nutrients, unless it is done several times during the growing season. Harvesting essentially puts the vegetation into an earlier stage of growth, thus increasing the net growth, and subsequently nutrient removal. Maximum nutrient removal may be accomplished by harvesting twice during the growing season, once at peak nutrient content and the second at the end of plant growth. Harvesting may also be necessary for mosquito control. Harvesting usually involves thinning out or trimming the vegetation, as opposed to clear cutting or stripping.

7 Erosion Prevention

The Edwards rules require that a technical report must be submitted which, among other things, requires that measures taken to avoid or minimize the in-stream effects caused by the regulated activity be described. In-stream effects include increased stream flashing, stronger flows, and erosion. It is widely recognized that development increases the rate and volume of stormwater runoff. These changes increase the rate of channel erosion downstream of the development. For instance, channel erosion accounts for up to 90% of the TSS load in urban streams. Measures taken to reduce TSS loads in runoff from the site often mitigate these impacts to a large extent.

Studies of the morphology and hydrology of Austin area creeks (Raymond Chan et al, 1997) indicates that majority of the erosion occurs during storms with return periods of less than one year. The study also indicates that relatively brief, intense storm events are responsible. Consequently, detention of the 1-year, 3-hour event with release of the captured water over a period of 24 hours will mitigate the most serious channel erosion problems. Table 7.1 lists the storm depth for each county for this size event.

Table 7.1 One-year, three-hour Storm by County

County	Precipitation (in)
Bexar	1.91
Comal	1.94
Hays	1.94
Kinney	1.68
Medina	1.84
Travis	1.93
Uvalde	1.72
Williamson	1.92

Example calculations indicate that the water quality capture volume required to meet the TSS load reduction (using sand filters and including the volume provided for sediment accumulation) is generally equivalent to about 1.8 inches of precipitation. Although this is less than the optimum volume, it is sufficient to capture all of the runoff generated by more than 90% of the storm events in this area. Consequently, all of the detention options (retention/irrigation, extended detention, wet basins, and sand filters) will provide substantial protection against stream channel erosion.

Grassy swales and vegetated filter strips do not provide significant protection against stream channel erosion resulting from development. Although stormwater infiltration in these BMPs can reduce to the total amount of runoff discharged, the volume reduction is generally not large because of the fined grained, low permeability soils in this area. Although not required in the rules, providing supplemental detention when using these types of BMPs would help prevent downstream erosion and flooding problems.

Channel and bank erosion can also occur where concentrated stormwater runoff discharged from a BMP or storm drain system enters a natural channel. At these sites, appropriate energy dissipation must be incorporated in the design.

8 Example Calculations

8.1 Introduction

The following example indicates the types and sizes of BMPs that would comply with the proposed Edwards rule requiring 80% reduction in the increase in TSS stormwater loading. Assumptions of this example are:

- The site is currently undeveloped (0% impervious cover)
- Soils are hydrological group D with an infiltration rate of 0.1 inch/hour.
- The proposed site area is 10 ac.
- The site is located in Bexar County
- No runoff enters the site from upgradient (or is directed around the development and does not enter the proposed BMPs)
- The impervious cover after development is 65%
- All runoff leaves the site at a single point

8.2 Background Load Calculation

The background load for undeveloped sites is calculated from:

$$L = A \times P \times 0.62$$

For the assumed conditions:

$$L = 10 \times 30 \times 0.62 = 186 \, {}^{lb}\!/_{yr}$$

Where:

10 = site area in acres
30 = Annual precipitation for Bexar County (Table 3.1)

8.3 Post Development Load

The load after completion of the proposed development is calculated by:

$$L = A \times P \times R_v \times 43$$

For the assumed conditions:

$$L = 10 \times 30 \times 0.52 \times 43 = 6{,}700\ {}^{lb}\!/_{ac}$$

Where:

10 = site area in acres
30 = Annual precipitation for Bexar County (Table 3.1)
0.52 = runoff coefficient for 65% impervious cover (Table 3.2)

8.4 Required Removal

Removal of 80% of the increase in TSS loading is calculated by:

Required Reduction = 0.8(postdevelopment load –predevelopment load)

For this example:

Required Reduction = 0.8(6,700 – 186) = 5,210 lb/yr

8.5 Example Capture Volume Calculations

8.5.1 Retention/Irrigation

Assume that retention/irrigation is the BMP selected for treatment of the stormwater runoff. Since these systems should be located offline, the appropriate equation for calculating load reduction is:

$L_R = L_I$ x F x Fraction of site treated x (TSS Removal Efficiency)

For this example, we are assuming that all runoff flows to a single outlet, which means that 100% of the site is treated. The TSS removal efficiency for retention/irrigation systems is 100% and L_I is the post development load (6,700 lb/yr). The required reduction (L_R) is 5,210 lb/yr. Consequently, the only unknown in the equation is F, the fraction of the stormwater load captured and the equation becomes:

5210 = 6,700 x F x 1.0 x (1.0)

Therefore, F the fraction of load that must be captured to achieve the 80% reduction is 0.78. Interpolating from Figure 3.2, the runoff depth associated with a fraction captured of 0.78 and impervious cover of 65% is just less than 0.5 inches. The capture volume of the retention basin is calculated by multiplying the runoff depth times the site area (10 acres in this example), so the required water quality volume is about 18,000 ft^3. This volume should be increased by 20% to allow for sediment accumulation between major maintenance activities so the total capture volume would be 21,600 ft^3.

The area required to irrigate this volume is calculated as:

$$A = \frac{12 \times V}{T \times r} = \frac{12 \times 21{,}600}{60 \times 0.1} = 43{,}200\, ft^2$$

In this example, 35% of the 10-acre site is pervious area (landscaping, etc.), which is equivalent to 152,500 ft^2. Therefore, there is sufficient area on the site for the irrigation system. Ideally, the irrigated area should include the entire pervious area to provide more effective use of the retained runoff.

8.5.2 Sand Filter System

Assume that a sand filter is the BMP selected for treatment of the stormwater runoff. Since these systems are generally locate offline, the appropriate equation for calculating load reduction is:

$$L_R = L_I \text{ x } F \text{ x Fraction of site treated x (TSS Removal Efficiency)}$$

For this example, we are assuming that all runoff flows to a single outlet, which means that 100% of the site is treated. The TSS removal efficiency for sand filters systems is 89% and L_I is the post development load (6,700 lb/yr). The required reduction (L_R) is 5,210 lb/yr. Consequently, the only unknown in the equation is F, the fraction of the stormwater load captured and the equation becomes:

$$5210 = 6{,}700 \text{ x } F \text{ x } 1.0 \text{ x } (0.89)$$

Therefore, F the fraction of load that must be captured to achieve the 80% reduction is 0.87. Interpolating from Figure 3.2, the runoff depth associated with a fraction captured of 0.87 and impervious cover of 65% is about 0.7 inches. Multiplying the runoff depth times the site area gives a water quality volume of 25,400 ft^3. The water quality volume should be increased by 20% to allow for sediment accumulation; therefore, the total capture volume is 30,500 ft^3.

8.5.3 Combination Grassy Swale/Extended Detention

Assume that grassy swales are used for conveyance of stormwater to an extended detention basin. In this case, there are two BMPs in series and their reductions are calculated separately. The load reduction due to the grassy swale is calculated by:

$$L_R = L_I \text{ x Fraction of site treated x (TSS Removal Efficiency)}$$

Assume, because of the site plan, only 50% of the area can be treated with grassy swales. The remainder of the storm runoff is transported to the detention facility in a traditional storm drain system. Therefore, the detention basin treats the runoff from the entire area, with 50% of the runoff pretreated with the grassy swale. When the site values are entered, the removal attributed to the swale is:

$$L_R = 6{,}700 \text{ x } 0.5 \text{ x } (0.70) = 2{,}345 \text{ lb}$$

The remaining load required to be removed by the extended detention basin is:

$$5{,}210 – 2{,}345 = 2865 \text{ lb}$$

For the extended detention basin, the capture volume to remove the remaining TSS must be calculated according to:

$$L_R = L_I \text{ x } F \text{ x Fraction of site treated x (TSS Removal Efficiency)}$$

The parameter L_I, the load to the detention basin is the total site load minus the amount removed by the grassy swale and is calculated as:

$$L_I = 6{,}700 – 2{,}345 = 4{,}355 \text{ lb}$$

Filling in the appropriate values gives:

$$2865 = 4{,}355 \text{ x } F \text{ x } 1.0 \text{ x } (0.75)$$

Therefore, F, the fraction of the runoff that must be captured and treated in the detention basin is 0.88. According to Figure 3.2, this corresponds to a runoff depth of about 0.72 inches. Multiplying the runoff depth times the watershed area gives a water quality capture volume of 26,100 ft^3. This volume should be increased by 20% to allow for sediment accumulation, therefore the total required capture volume is 31,400 ft^3. Although this capture volume is about the same as required by a sand filter system without no grassy swale, extended detention basins are less expensive to construct and the maintenance associated with the filtration basin is avoided.

9 Bibliography

Barrett, Michael E., Quenzer, Ann M., and Maidment, David R., 1998a, *Water Quality and Quantity Inputs for the Urban Creeks Future Needs Assessment*, report to the City of Austin, Texas, Center for Research in Water Resources, The University of Texas at Austin.

Barrett, Michael E., Keblin, Michael. V., Walsh, Patrick M., and Malina, Joseph F., Jr., 1998b, Performance comparison of highway BMPs, in Watershed Management: Moving from Theory to Implementation, Denver, CO, May 3-6, 1998, pp. 401- 408.

Barrett, M.E., Keblin, M.V., Walsh P.M., Malina, J.F., Jr., and Charbeneau, R.J., 1997, *Evaluation of the Performance of Permanent Runoff Controls: Summary and Conclusions*, draft report to the Texas Department of Transportation, Center for Research in Water Resources, University of Texas, Austin, Texas.

Barrett, M.E., Zuber, R. D., Collins, E. R. III, Malina, J. F., Jr., Charbeneau, R. J., and Ward, G.H., 1995, *A Review and Evaluation of Literature Pertaining to the Quantity and Control of Pollution from Highway Runoff and Construction*, 2nd Edition, Center for Research in Water Resources Technical Report 239, The University of Texas at Austin.

Brown, W. and Schueler, T., 1997, *National Pollutant Removal Performance Database for Stormwater BMPs*, Center for Watershed Protection, Silver Spring, Maryland.

Chang, M. and Crowley, C.M., 1993, "Preliminary observations on water quality of storm runoff from four selected residential roofs," *Water Resources Bulletin*, Vol. 29, No. 5, pp. 777-783.

City of Austin, 1997, *Environmental Criteria Manual*, Drainage Utility Department, Austin, Texas.

Dorman, M.E., Hartigan, J., Steg, R.F., and Quasebarth, T.F., 1996, *Retention, Detention and Overland Flow for Pollutant Removal from Highway Stormwater Runoff*, FHWA-RD-96-095, Versar Inc., Springfield, VA.

Glick, Roger, Chang, George C., and Barrett, Michael E., 1998, "Monitoring and evaluation of stormwater quality control basins," *in Watershed Management: Moving from Theory to Implementation*, Denver, CO, May 3-6, 1998, pp. 369 – 376.

King County, 1996, *Surface Water Design Manual* (Draft), King County Surface Water Management Division, Washington.

Livingston, E.H., Shaver, E., and Skupien, J.J., 1997, *Operation, Maintenance, and Management of Stormwater Management Systems*, Produced by the Watershed Management Institute, Ingleside, Maryland.

Lower Colorado River Authority, 1998, *Nonpoint Source Pollution Control Technical Manual*, Austin, Texas.

Larkin, T.J., and Bomar, G.W., 1983, *Climatic Atlas of Texas*, Texas Dept. of Water Resources (now Texas Water Development Board), Austin, Texas.

North Central Texas Council of Governments, 1993, *Storm Water Quality Best Management Practices for Residential and Commercial Land Uses*, Arlington, TX.

Raymond Chan & Associates, et al, 1997, *Regulatory Approaches for Managing Stream Erosion*, report to the City of Austin Drainage Utility Department.

Schueler, T.R., 1987, *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*, Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, DC.

Schueler, T.R., Kumble, P., and Heraty, M., 1992, *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Nonpoint Source Pollution in the Coastal Zone*, Anacostia Research Team, Metropolitan Washington Council of Governments, Washington, DC.

Urbonas, B.R., et al, 1992, *Urban Storm Drainage Criteria Manual, Volume 3 – Best Management Practices, Stormwater Quality*, Urban Drainage and Flood Control District, Denver, CO.

Washington State Department of Transportation, 1995, *Highway Runoff Manual*, Washington State Department of Transportation, Olympia, Washington.

Water Environment Federation and ASCE, 1998, *Urban Runoff Quality Management*, WEF Manual of Practice No. 23 and ASCE Manual and Report on Engineering Practice No. 87.

Young, G.K., et al, 1996, *Evaluation and Management of Highway Runoff Water Quality*, Publication No. FHWA-PD-96-032, U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning.